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AN EXPERT SYSTEM FOR THE CIVIL ENGINEERING IN-SERVICE WORK PLAN

THESIS

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Captain, USAF

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Abstract

Civil Engineering managers make many decisions each day which could be aided using expert system technology. One of the most important decision processes affecting CE operations is the scheduling of work orders to be accomplished each month. A good work order schedule, or In-Service Work Plan (IWP), can ensure that material and manpower resources are fully utilized, that base facilities are properly maintained, and that customers are satisfied.

The purpose of this research was to build and test a PC-based prototype expert system to schedule the IWP. Expanding on previous research, a multiplicative weighting technique was developed to provide relative scores for each work order awaiting scheduling. Factors used in assigning scores include work order priority, command interest, weather dependency, bottleneck shop availability, and work site availability. The expert system then scheduled work orders against available shop hours, attempting to scheduled the work orders with the highest scores first.

The prototype produced a three-month IWP schedule in thirty minutes, compared to the four man-weeks required to produce a one-month schedule at the test location. The system ensured that high priority work was scheduled first and that bottleneck shops were fully utilized.

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I. Introduction

Overview

Expert systems are computer programs that use some form of specialized reasoning to solve difficult problems well, in a narrow domain (1:195). Knowledge-based expert systems employ human knowledge and experience to solve complex problems electronically (2:11).

Although books now store the largest volume of knowledge, they only retain it in passive forms (2:11). "Before the knowledge stored in the books can be applied, a human must retrieve it, interpret it, and decide how to exploit it for problem-solving" (2:1). Most computer information systems today provide the same function: they store information and provide a mechanism for retrieving, displaying, and printing the information when requested. Managers must apply the information to their particular problem domains to make decisions.

Air Force Civil Engineering (CE) managers make many important decisions based on retrievals from their Work Information Management System (WIMS) computers. This system was designed by Air Force Civil Engineering for tracking all types of work, costs, material, labor, and other important information within the CE organization. It is basically a filing system. Information is put in and, through specific queries, the same information is retrieved. WIMS provides managers with the basic tools for decision-making, including the information and some general summary statistics. However, sorting through the generated reports is a time-consuming process. Incorporating expert systems into some of the WIMS applications could help managers make faster, more effective decisions.

Work scheduling in the operations branch, which contains most CE resources used for base maintenance, is one of the most critical problems faced by CE squadrons. Work schedulers must coordinate work requirements with personnel resources, material, and equipment. CE squadrons could see a 15% increase in productivity if shop personnel were scheduled more effectively (3). The Inservice Work Plan (IWP) is used to time phase work to be completed by the shops. The IWP is of great concern for CE managers because estimated completion dates for projects are given to customers based on the generated schedule. Unfortunately, the current method for generating the IWP is not very accurate and has led to many bad estimates, disappointed customers, and poor decisions (3). Captain Chris Hazen's thesis concluded that job order and work order management, the key components of the IWP, have some of the greatest potential for the application of an expert system in CE (4:58).

Purpose of Research

The purpose of this study is to develop an expert system to help Air Force Civil Engineering manage the base Inservice Work Plan. The expert system should help improve the IWP by projecting a schedule three months into the future. A three-month schedule is highly desirable since it helps CE managers provide realistic start and completion dates to customers. To provide such a schedule, the expert system will draw information from several databases which would normally have to be reviewed separately by the IWP programmer. Thus, the expert system should also provide a schedule much more quickly than the IWP programmer can currently provide with the assistance of WIMS. Finally, the expert system should be flexible enough to show how insertions of new work into the work order system will impact the schedule.

Scope

Many potential areas exist within Civil Engineering for applications of expert systems. This thesis concentrates on the Inservice Work Plan.

This research describes the development of an expert system for scheduling the IWP at a "typical" Air Force installation. Strategic Air Command (SAC) and Tactical Air Command (TAC) have shifted their CE Operations branches away from centralized control through the implementation of Readiness and Ownership Oriented Management (ROOM) and Combat Oriented Results Engineering (CORE) respectively. This study focuses on the more standard structure of organizations within Military Airlift Command (MAC) and Air Force Logistics Command (AFLC).

This research demonstrates the usefulness of an expert system for the IWP, and shows how expert system tools could be used in Civil Engineering.

II. Literature Review

Overview

This chapter reviews the current literature concerning the development and application of expert systems (ES), in particular, the potential for applying expert systems to the IWP scheduling process. It defines expert systems, describes several techniques for their development, and outlines some successful applications in business and the military. The IWP concept is described and previous efforts to incorporate expert systems into the CE operations decision process are discussed.

What are Expert Systems?

Knowledge-based expert systems employ human-like heuristics to solve problems that ordinarily require human intelligence. Expert system computer programs control the application of the heuristics and known facts to create new knowledge. Most computer programs today use algorithms to transform and manipulate data in a structured format to solve problems. These algorithms are sequential, repetitive calculations designed to answer structured problems.

> Because much human knowledge consists of elementary fragments of know-how, applying a significant amount of knowledge requires new ways to organize decision-making fragments into useful entities. Knowledge-based expert systems collect these fragments in a knowledge base and access the knowledge base to reason about specific problems. (2:11)

Expert systems gather these fragments from the expert in a field and assemble the information into heuristics. The heuristics describe how information and facts can be manipulated to solve a particular problem.

Berztiss believes that the primary function of ES is to support routine decision making so managers have time for the more important strategic planning (5:222). Often, top management and specialist expertise are scarce, and the expert's time is extremely valuable. Such shortages can be overcome with the use of ES, which can quickly provide expertise at any location (1:196-199).

Many potential benefits from expert systems have been reported. These include improved decision making, more consistent decision making, reduced design or decision making time, improved training, operational cost savings, better use of an expert's time, improved product quality or service levels, and the capture of rare or dispersed knowledge (6:41).

Development of Expert Systems

As with most complex problems, the development of knowledge-based expert systems is most successful with a structured approach. Freiling and others recommend a step-by step process for starting a knowledge engineering project and developing a prototype (7:155). Their steps include:

1. Familiarization with the problem domain to determine the scope and complexity of the task. This

involves gaining a working knowledge of the domain and describing the general relationships relative to the problem. A paper knowledge base can contain representative expressions of the facts and rules the experts may use. The expressions must be clear, unambiguous descriptions of relevant knowledge.

2. Organizing knowledge in a compact format more convenient for automation. Typically, statements follow the format of rules in an IF-THEN structure. Figure 1 provides an example of this rule-based structure.

3. Determining the representation method for the knowledge acquired. The internal knowledge base formats could include database files and spreadsheets.

4. Acquiring knowledge. This step is the actual process of gathering information, facts, heuristics, and other knowledge from the expert. The knowledge is translated into a format ready to be processed by the expert system under construction.

5. Determining the control mechanisms which guide the computer program through the facts and heuristics to arrive at a solution. The resulting strategy is controlled by the expert system's inference engine.

6. Designing the interface. The interface is the link between the expert system users and the expert system. Therefore, it must be able to display or print the information required by the user, such as the solution to the problem and the steps taken to arrive at the solution.

The interface must be complete, yet easy for users to understand. The resulting product of this stage is a prototype interface (7:155-159).

Rules for Approving/Disapproving Checks

```
IF      Has_Store_Credit_Card = Yes
  AND   Bad_Debt_Customer = No
  AND   Check_Amount <= 100
THEN    Approval = Ok

IF      Has_Other_Credit_Card = Yes
  AND   Bad_Debt_Customer = No
  AND   Has_Local_Drivers_License = Yes
  AND   Check_Amount < 50
THEN    Approval = Ok
ELSE    Approval = Not_Ok
```

Figure 1 Example of Expert System Rules

Captain Randy Eide recommends similar procedures which focus on knowledge acquisition for expert systems for Air Force Civil Engineering. His method involves the following eight steps:

1. Become familiar with the domain of interest.

2. Select domain experts.

3. Interview domain experts to extract initial knowledge base.

4. Display the knowledge gathered in the first interview in IF/THEN rule format.

5. Interview domain experts a second time to verify initial interpretation of knowledge rules.

6. Finalize knowledge base in procedural rule format.

7. Automate knowledge base through an expert system shell.

8. Validate the expert system (8:28).

Eide recommends using instruction manuals, pertinent regulations, journals, documentation, or other appropriate sources to gain familiarity with the problem domain, as required by step 1 (8:28-29). Domain experts, step 2, should be selected from the most valuable experts in a particular area (8:29). For steps three and five, Eide suggests the interview take place in the expert's work area so any references or visual representations used by the expert can be readily available during the interview. He also recommends an open-ended interview format if the interviewer has sufficient understanding of the domain, thus allowing a greater flow of information from the expert (8:30).

The iterative nature of the development process is shown in Figure 2. The knowledge engineer collects the knowledge from the expert and develops a prototype system. The prototype is then tested using several cases. The results of these cases are then validated to determine if the prototype made the same decisions as the expert. New knowledge in the form of rules and facts are added to the prototype until the results are satisfactorily consistent with the decisions made by the expert (9).

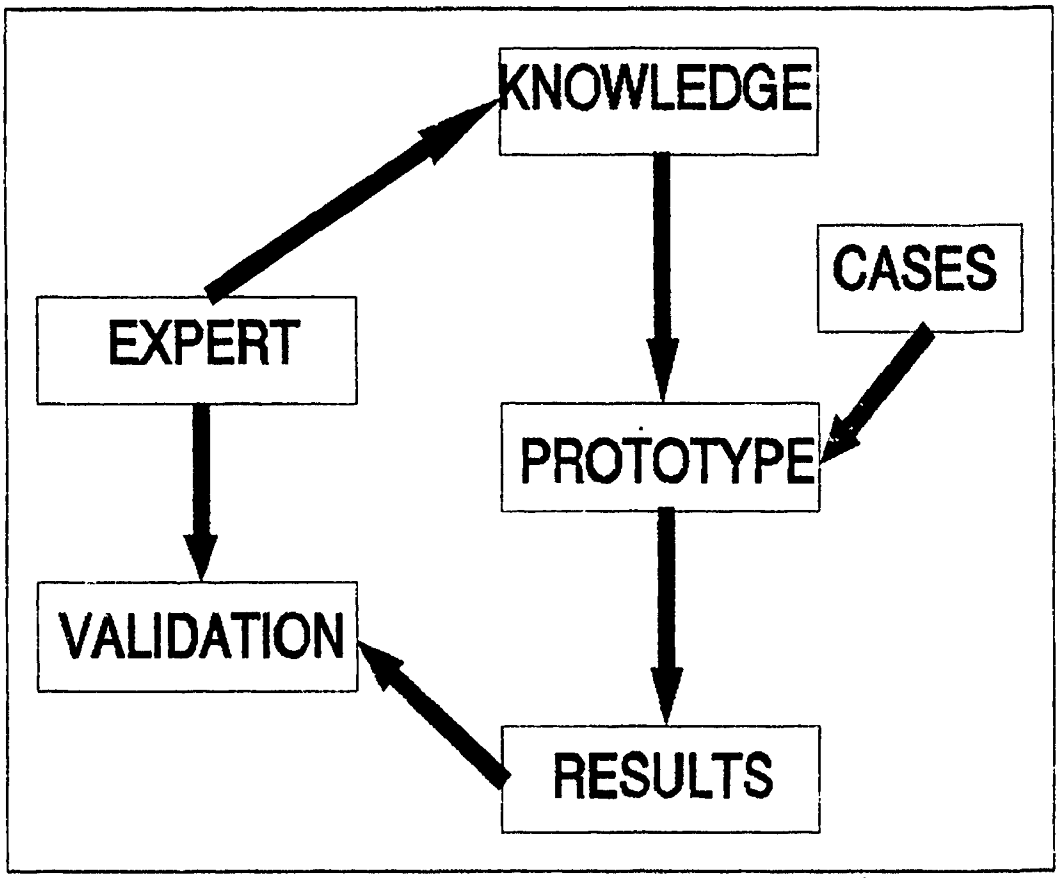

Figure 2 Expert System Development Process (9)

Expert System Shells

An expert system shell is a computer program that simplifies the creation of rule-based applications. The user can crate his own expert system just by providing the knowledge and logic of the decision process. The shell provides the user interface, the control structure, rules structure, fact representation, and the inference engine, in one package that allows specific applications to be created

(9). A few expert system shells are: VP-Expert, Knowledge Pro, EXESYS, M1, LEVEL V, and Logic Tree. All are commercially available and offer an easier method for implementing an expert system than formal languages such as Cobol, Fortran or Ada. The major components of expert system shells are shown in Figure 3.

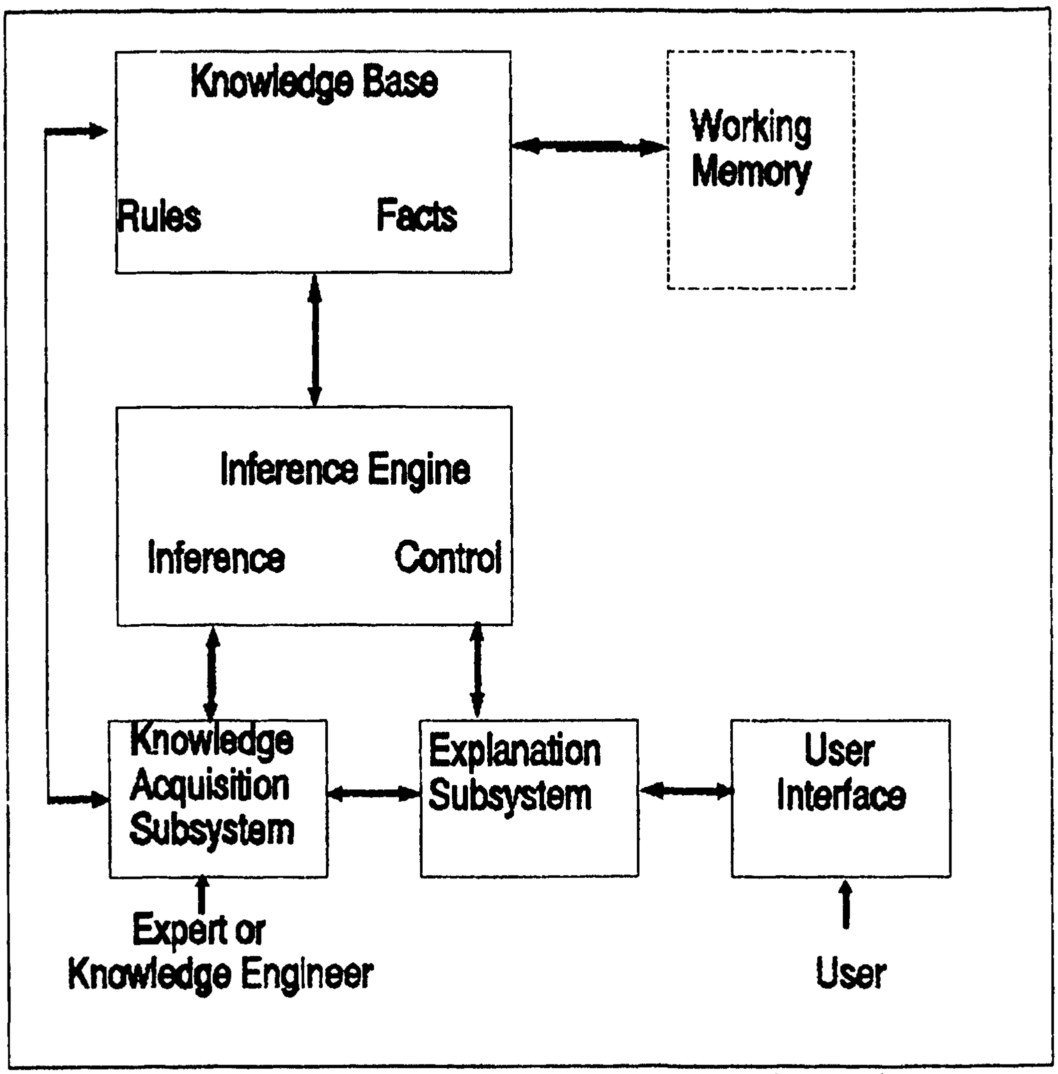

Figure 3 Components of an Expert System (10:49)

The IWP Concept

CE shops spend available man-hours on several types of work, including job orders, recurring maintenance, and work orders.

Job Orders. According to AFR 85-2, Civil Engineering Operations Management, a job order is work which does not require detailed planning and can generally be completed quickly (11:24). Job orders can be classified in one of three ways: emergency, urgent, and routine. Any work required to correct an emergency situation that is detrimental to the mission or reduces operational effectiveness is an emergency job order. Urgent job orders include work that is not an emergency, but should be accomplished within five workdays of receipt, or within five workdays of receipt of material. This work typically includes the elimination of fire, health or safety hazards. Routine job orders identify work that is relatively small-scale in nature and not qualified as emergency or urgent work (11:24).

Recurring Work. Recurring work includes all preventive maintenance needed to prevent breakdown of critical facilities,

equipment, and utilities (11:49). This includes such tasks as replacing air filters in air conditioning and heating units, changing oil in generators, and changing belts on various types of equipment.

Work Orders. Work orders are typically more complex than job orders, require work to be accomplished by several shops, and require extensive planning and material control (11:32). Work orders are assigned a priority based on the impact of the work on the installation's mission, or safety considerations. The following is the priority system required by AFR 85-2:

1. Priority I - Mission. Work in direct support of the overall mission of the base or tenant mission that if not done would reduce operational effectiveness.
2. Priority II - Safeguard Life and Property. Work needed to give adequate security to areas subject to compromise; to eliminate health, fire, or safety hazards; or to protect valuable property or equipment.
3. Priority III - Support. Work which supports the mission or prevents a breakdown of essential operating or housekeeping functions.
4. Priority IV - Necessary. Not qualifying for higher priority (11:20).

There are seven major steps in the life of a work order. These steps include:

1. An organization submits a work request to CE customer service.

2. The work request is approved as being a valid work requirement, and becomes a work order. It is then put in the queue to be planned.

3. The work order is planned, then queued for material order.

4. Materials are ordered for the work order. This occurs when funds are allocated for the job.

5. Work order is material complete and awaiting manhours from the necessary shops.

6. Shops are scheduled to accomplish the work.

7. When all work is complete, work order is closed out.

Work requests are generally approved by the Chief of Production Control or Chief of Resources and Requirements. Depending on the cost of the work and regulations at a particular installation, a work order might require approval from the Chief of Operations of the Base Civil Engineer. Typical approval levels might be $50,000 for the Chief of Production Control, $100,000 for the Chief of Resources and Requirements, $150,000 for the Chief of Operations, and $200,000 for the BCE.

Planning. Planners in Civil Engineering Operations are typically craftspeople who have significant experience working in the shops, but little formal engineering training. Their job is to determine what materials will be required for a work order, and how much labor will be involved from each shop. Thus, it generally requires a structural planner to work on the structural portion of a work order, an electrical planner to work on the electrical portion, etc. Therefore, the right type of planners must be available to plan a particular work order.

Planners are aided in their task by several functions included in WIMS. These include the Civil Engineering Materials Acquisition System (CEMAS). Through CEMAS, a planner can build a Bill of Materials for a work order, estimate the costs and track the arrival of all materials. There is also a book of standard labor estimates built into WIMS which the planners use to estimate the manhours required of each shop for a work order. The estimates obtained by the planners for labor and materials are generally fairly accurate.

Finances. Funding takes place for a work order in a variety of ways. Some facilities on Air Force installations have their own funding source for maintenance and repair. These include the medical facilities, military family housing, and the Airlift Support Fund (at MAC bases), which is used for any facility directly supporting the airlift mission. These "pots of money" are given separate authorizations by Congress than the pot used for Operations and Maintenance (O&M) on the rest of the base, and are relatively unconstrained. Thus, it is easy to fund work requirements for these types activities.

O&M funding must be split among base units to keep them operating. Flying squadrons, transportation squadrons, aircraft maintenance, security police and CE all compete for the same money. It is this type of money that CE uses to buy materials required for work orders, and to pay for the labor involved in accomplishing them. Therefore, CE squadrons have had to become increasingly aware of funding availability before beginning major projects, as O&M funding has been reduced.

Once materials have been received, a work order is scheduled against available hours for the necessary shops during a particular month. The work is then accomplished as described in the plan. Once all work is completed, costs are totalled and the work order is closed out.

In-Service Work Plan. The Inservice Work Plan is designed to enable CE squadrons to accomplish as much work as possible by matching their resources against the vast requirements. The two main objectives are to complete all mission-critical work, and to keep customers, i.e. all base occupants, satisfied. A well-managed IWP can establish credibility for a CE squadron by providing an accurate and timely schedule of work (12:1).

From the point of view of the base community, the IWP can help by allowing CE to specify dates when a project should commence and when it should be completed. A CE squadron quickly loses credibility among a base population when these commitments are not met (12:1).

Within the CE unit, morale will remain high if priorities and schedules remain firm. When priorities are in flux, schedules have no meaning, workers are constantly pulled from one job to another, and few jobs are completed in an orderly fashion. A good IWP forces priorities and schedules to be established and followed (12:1).

The IWP is prepared approximately two weeks before the beginning of a particular month using the following steps:

1. Project the number of manhours available for each shop for the month.

2. Estimate the number of manhours reserved for job orders, recurring work, and training.

3. Determine which in-progress work orders will continue to require manhours during the month, and schedule accordingly.

4. Based on priorities and remaining available manhours, schedule new work to be started (12:2-3).

In order for the plan to be successful, new work scheduled in Step 4 must be fully planned, with materials projected for arrival by the scheduled start date. A schedule can go wrong if work is scheduled before a job is fully planned, if work is scheduled before a job is material-complete, if estimates for available manhours are off, or if estimates for job orders or recurring work are wrong (3).

Previous Studies

Several previous studies by AFIT students have explored the application of expert systems in Civil Engineering. These studies and their findings are summarized below.

Expert System Application Areas. Captain Hazen conducted research to determine criteria for applying an expert system to a problem. He also surveyed Civil

Engineering managers to determine in what areas they thought an expert system would be beneficial.

Based on the responses given by the managers interviewed, and through his own additional research, Hazen concluded that job order/work order management was one of five areas in Civil Engineering that had the greatest potential for the application of an expert system.

On a thirty point scale, job order/work order management ranked first of all areas included in the study, scoring 26 points. This application was followed by design schedule management (20 points), beddown of new aircraft systems (19 points), and facility constraints on aircraft design (18 points) (4:52). Hazen's study clearly shows that CE managers would like to have a better method for scheduling job orders and work orders, and that such an application meets the criteria for the implementation of an expert system.

Work Prioritization Methods. Captain Lillemon conducted surveys to determine what methods were being used to prioritize CE work. He developed a model of the tasks included in the work order decision process. Figure 4 lists these tasks, and shows where the bulk of his research was focused, in relation to this study.

Capt Lillemon surveyed Civil Engineering managers at 84 major installations within the continental United States (with a return rate of 71 percent) (13:51). His research determined how CE organizations prioritize work orders.

Table 1 shows the methods for work order ranking used by the respondents.

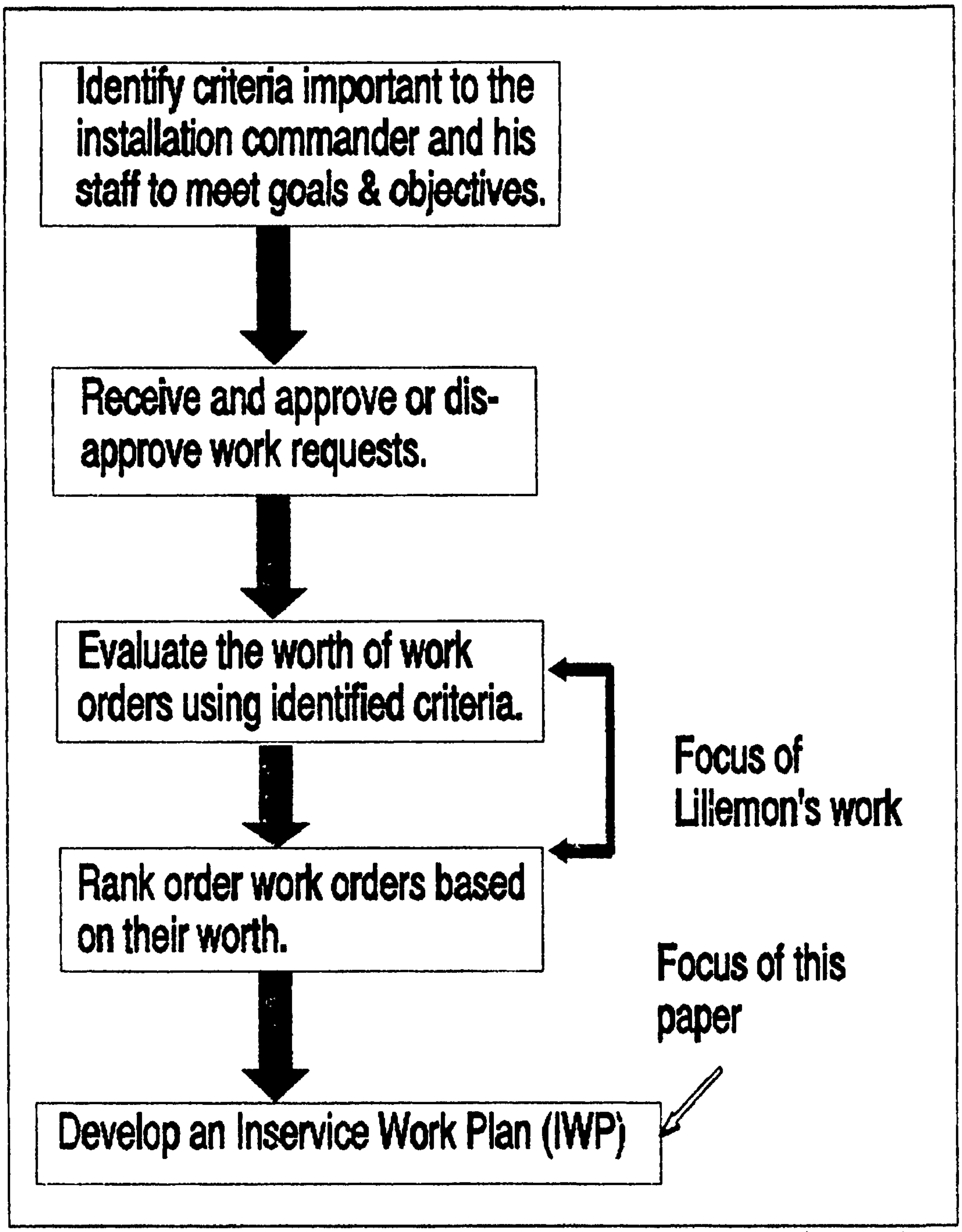

Figure 4 Tasks in Work Order Decision Process (13:23)

TABLE 1

REPORTED USE OF EACH WORK ORDER PRIORITY SYSTEM (13:57)

Priority System Used	Number of Respondents	Relative Frequency (percent)	Respondents' Ranking of Priority System
Weighting	2	1.7	4
No System	3	2.5	
Cmd Driven	13	11.2	6
Base Panel	16	13.8	2
BCE Panel	16	13.8	2
Engr Judgement	25	21.6	1
Checkbook	44	37.9	1

The Checkbook method was the most frequently used by the respondents, and tied with engineering judgement as the preferred method. In his thesis, Lillemon described the Checkbook method as follows:

> A block of manhours is allocated to each organization monthly based on factors such as organization size and total facility square footage occupied by the unit. As with a checkbook, the unit is free to request and have work accomplished up to the amount allocated to them monthly. Typically, units are free to negotiate with each other to make up deficits for desired work. Variations of the checkbook method may allocate number of work orders rather than manhours (13:67).

The Engineering Judgement method was reportedly used with the second highest frequency, and was tied for first as the most popular method among the respondents (13:57). Lillemon described the Engineering Judgement method as follows:

> The BCE combines prior experience and judgement to set work order priorities using the four-category priority system recommended by AFR 85-1. Typically, BCE uses First-in-first-out (FIFO) and reacts to Commander's special interest within each category. A variation of this system permits the Chief of Operations or Requirements to do most of the prioritizing, usually using AFR 85-1 guidance, FIFO and professional judgement (13:79).

Several of the respondents indicated using Engineering Judgement in combination with another method in Table 1. The other methods were used less frequently and were ranked as less practical by the respondents.

Lillemon concluded that, while the Checkbook method was the most useful, an analytical technique would aid decision makers no matter which method is used. He proposed the Analytical Hierarchy Process (AHP), a model which performs a pairwise analysis of competing work orders against a set of quantifiable criteria. The result is a ranked list based on the relative scores of each work order (13:33).

For bases using the Checkbook system, this technique could be applied to each organizations list of valid work orders. For bases using any of the other methods, the AHP could help decision makers by providing a quantifiable means for ranking work orders (13:131). If such a system could be automated, it could provide visibility to customers, save manhours, and permit a schedule to remain intact by providing criteria to measure proposed insertions.

Lillemon suggests four primary criteria for measuring a work order in the AHP. The first is Mission as defined in

AFR 85-1 with Priority I, II, III and IV. The second is Infrastructure, or type of work performed, either maintenance, repair or construction. The third criteria is Quality of Life, which can be equated to Command Interest. The values can be set by the Wing Commander, Base Commander, Directorate, or Other Commander. The fourth criteria is Safety, and takes the value of the Risk Assessment Code (RAC) assigned to a project (based on AFR 127-12). Each of the values in each criteria has a corresponding weighting scores. The sum of all weighting scores is then calculated to determine the work order score (13:121-125).

A scoring technique such as Lillemon's, when used in conjunction with management expertise, would be a valuable method for ranking work orders. Expert judgement could be used to determine what criteria are important for ranking work orders, and could also be used in conjunction with base CE panels to determine what weights should be assigned to each criteria. Such a system could be automated with an expert system fairly easily.

<u>Expert System Work Approval Process.</u> Captain Eide applied an expert system to determine how an approved work request should be accomplished (i.e., with CE resources by job order or work order, requestor's resources through self-help, or by government contract). His primary focus was to establish procedures for gathering expert knowledge for creating expert systems for Air Force Civil Engineering applications. He tested his method by building an expert

system to approve or disapprove work requests submitted to CE squadrons, and to determine the appropriate method for accomplishing the approved work.

Capt Eide successfully accomplished the eight steps described earlier in this chapter (in the section "Developing an Expert System"), and produced a working expert system. The experts he selected were recommended by HQ AFLC and HQ SAC. His interviews with the experts allowed him to produce a sufficient knowledge base with which to build an expert system. The decisions produced by his expert system were validated against the decisions made by his experts, with only a few minor discrepancies reported.

This same type of approach can be used to build an expert system for the scheduling of the IWP for Civil Engineering.

Expert System for the IWP. Captain Willard attempted to build an expert system for creating the IWP schedule. His efforts were only partially successful, for several reasons. First, Capt Willard overused the query function, prompting the user for a substantial amount of information. Some of the information could be read directly from a database, saving the developer from creating a complex user interface.

> When the system queried for the number of man-hours required for each category of work order, that is, safety, command interest, and so forth, the researcher was forced to enter an 'average' number of manhours per work order category. The prototype made no provision for entering individual manhour requirements for each work order and so their specific identity was lost (14:41).

The incorporation of a work order data base which the system could read from could have helped solve this problem.

Capt Willard's prototype was "primitive at best" and did not incorporate any complex rules such as those that would be used by an IWP scheduler. His repeated attempts to add complexity to the system were unsuccessful (14:41). He did, however, consider some of the important factors used in developing an IWP schedule. The factors he listed include:

1. Weather-dependent work orders
2. Safety related work orders
3. Priority 1 work orders
4. Command interest work orders
5. Time in the system
6. Direct mission support work orders
7. Earliest promised completion dates (14:33)

Capt Willard's prototype was able to provide a "skeleton" schedule, telling the scheduler how many of each type of work order could be scheduled for a particular month, but the scheduler had to manually determine which work orders of each category to schedule (14:41-42).

Summary

Current literature indicates great promise for implementing an expert system for the IWP. Large numbers of applications of ES have been used successfully in a wide variety of areas. In addition, a vast array of tools exist for developing expert systems. Previous studies provide excellent guidance in methods of ranking work orders to be included in the IWP, and for acquiring knowledge necessary from experts to create a working expert system.

III. Research Method

Overview

This chapter describes a combination of several techniques necessary tc develop an expert system for the Civil Engineering In-house Work Program (IWP). These techniques include interviews and other data collection methods, modeling, and prototype development and testing,

The following research questions guided the study:

1. Who are the real IWP experts who can contribute the knowledge to create an expert system?

2. How are demands for job orders, recurring work, training, and IWP manhours estimated?

4. How are work orders prioritized?

5. Are estimates for required work order manhours accurate enough for IWP scheduling?

6. How should the IWP process be modelled?

7. What expert system shells would be most effective for creating the expert system?

8. What will determine the validity of the expert system?

Step 1 - Domain Familiarization

The first step in this study involved familiarization with the problem domain. This included studying the relevant Air Force regulations to gain an understanding of the IWP process, reviewing course material which pertained to the IWP from the AFIT School of Engineering and Services, and running programs and reading the relevant documentation on WIMS to understand the current procedures used to schedule the IWP.

Step 2 - Expert Interview

The second step involved interviewing an expert, an experienced base level IWP programmer, to understand his method for scheduling the IWP. During a two-day interview period, the researcher developed graphic models of the decision process based on the method described by the expert. These models were continuously updated as the expert provided more depth in the discussion of the process, until a final model was agreed upon.

This expert was one of the individuals recommended during telephone interviews with Air Force Major Commands.

Step 3 - Prototype Development

Using the model derived during the interview with the expert, a prototype expert system was developed. The system was created using an expert system shell as described in Chapter II. The intent was to build the prototype in such a way that developing a full-scale COBOL program which would perform the same functions in the WIMS environment would be a relatively easy follow-up task.

Step 4 - Test and Evaluation

The system was tested using an active database from an Air Force Civil Engineering Squadron. The schedule produced by the system was compared with the schedule produced by another experienced IWP programmer. This second IWP programmer was recommended for the study by a different major command.

IV. Results and Findings

Overview

The first section of this chapter describes the selection of the system experts. The second section discusses the interview process and the information obtained from the expert. The third section discusses the design of the expert system. The final section describes the performance of the prototype system.

Expert Selection

Telephone interviews conducted with the Production Control specialists for Civil Engineering at HQ MAC and HQ AFLC identified Mr John Foster of Dover AFB, DE (MAC) and Mr Arlyn Johnson of Wright-Patterson AFB, OH (AFLC) as base-level experts.

Because of the proximity of this research to WPAFB, Mr Johnson is used for the more extensive, iterative system validation process and Mr Foster provided information to create the initial knowledge base.

Results of the Interview

As suggested by the work of Freiling and others (7:155-159), and Eide (8:28), the first step in the interview process was gaining familiarity with the general workings of the IWP before meeting with the expert.

The first source was AFR 85-2 which discusses the management of Civil Engineering Operations. The second source of information was the set of class notes given to students of the CE Operations Management short course at the Air Force Institute of Technology School of Civil Engineering and Services (12). In addition, the IWP programs currently available on the WIMS were studied to determine how they can be used in the scheduling process. These sources, in conjunction with the researcher's own experience with base-level CE Operations, provided the necessary foundation of knowledge to conduct a meaningful interview, without wasting the precious time of the experts on very basic information.

Two days of very successful interviews were conducted in Mr Foster's work area at Dover AFB. As expected, the knowledge acquisition was a building process in which layers of decision details were added to the overall IWP scheduling process.

IWP Scheduling Process. The interview process itself led to the development a detailed model which described the steps required to build an IWP schedule. At its most basic level of simplification, the process of scheduling the IWP is represented in Figure 5. The basic premise is to match available resources with work requirements. Thus the first step is to determine the availability of resources. In this case the number of manhours available for work order performance is calculated. The next step is to determine which work orders are ready to be scheduled. Finally, the resources are matched against the requirements to determine what work can be accomplished (15).

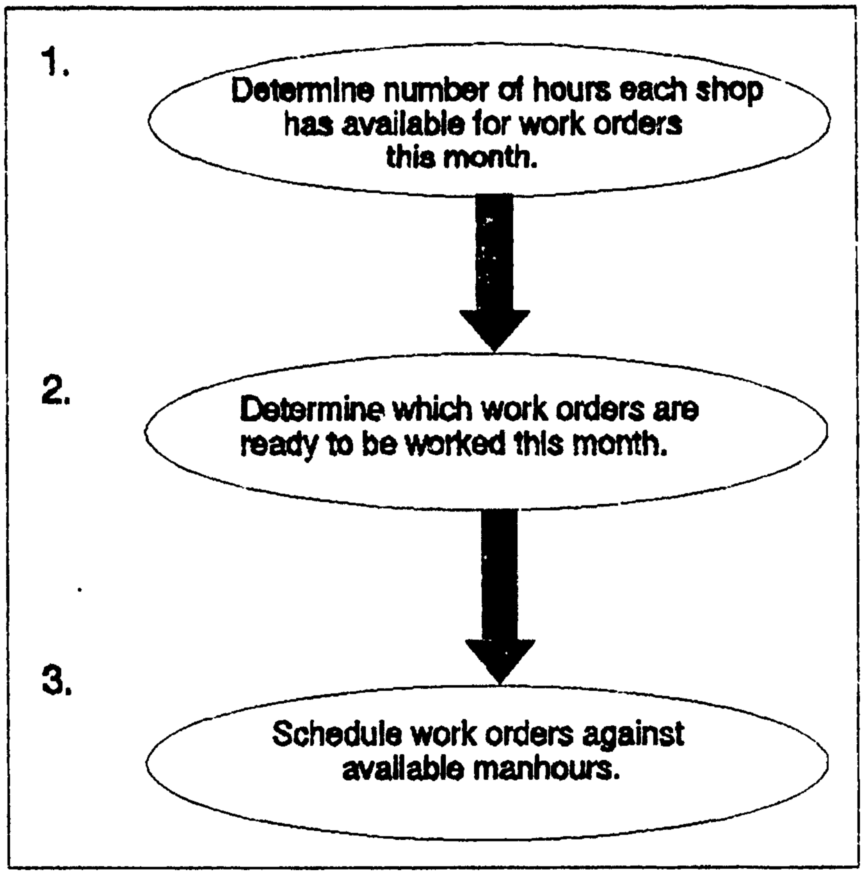

Figure 5. General process of scheduling the IWP

Each of these three steps can be broken down into greater levels of detail. To determine the number of available hours each shop has for accomplishing work orders, the IWP scheduler enlists the aid of the shop foremen, as well as historical data in WIMS. The process is broken down in Figure 6.

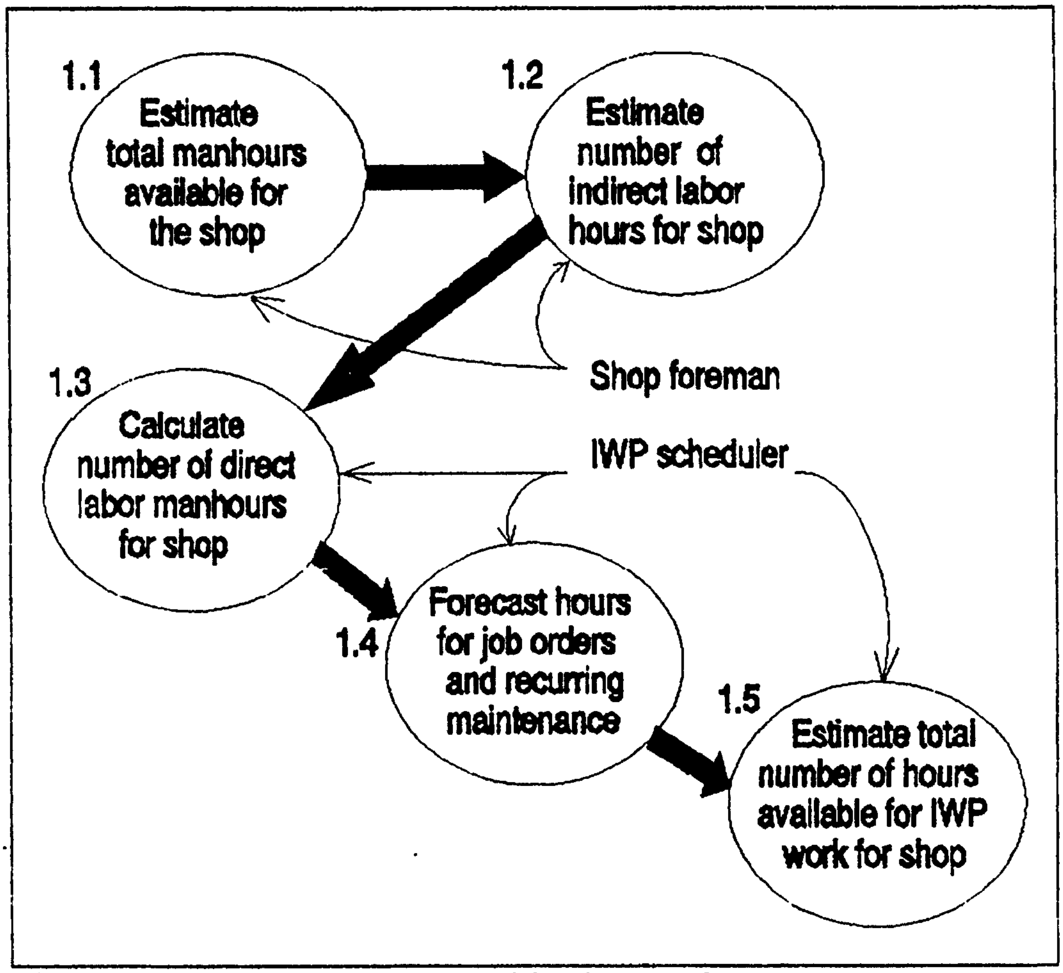

Figure 6 Estimating available hours for IWP work for each shop

Estimating Available Hours. First, forms are filled out by each of the shop foremen. The foremen forecast the total number of manhours he will have available for the month being scheduled. A copy of the form used by the Dover CE squadron is at Appendix A. The foremen base these numbers on the number of personnel assigned to their shop, adjusting for any personnel borrowed from other shops or loaned to other shops. The foreman then estimates the number of indirect labor hours for his shop. Indirect labor includes such activities as training, exercises, supervision, and leave. By subtracting the number of indirect hours from the total available hours, the shop foreman is able to forecast the total number of manhours available for direct labor for the month.

Next, the IWP scheduler estimates the number of hours each shop will require for job orders and recurring work for the month. The scheduler prepares this estimate by using historical data in WIMS. Historical labor data provides the number of hours spent on each type of work classification (known as Labor Usage Classification (LUC) Code). The IWP scheduler retrieves the data for the previous three years of the current month, and averages the hours spent on each LUC Code. For example, the scheduler must estimate the number of manhours the carpenter shop will spend on emergency job orders for September, 1991. He prepares his estimate by taking the average of the manhours spent on emergency job orders in September of the years 1988, 1989, and 1990.

These estimates are calculated for emergency job orders, urgent job orders, routine job orders, and recurring work for each shop - a time consuming process. The total of these estimates is subtracted from the total direct labor estimate for the month to give the projected number of hours available for the shop to accomplish work orders.
This is the figure the IWP scheduler uses to schedule IWP hours for each shop.

Determining Work Requirements. The Chief of Resources and Requirements, with advice from the Chief of Planning, generally determines which work orders to start planning. The decisions are based on the availability of planners with the necessary skills, and the priority associated with a given work order. This priority is often subjective in nature; it is determined by rating the need for a particular work order relative to other work orders.

Materials are ordered for a work order when the plan is complete and funds are available. Once all materials are received for a work order, the work order is put in the queue for the IWP.

The Chief of Operations and the Chief of Resources and Requirements generally determine which work orders to release to the IWP scheduler, who then tries to determine in which month to schedule them. Decisions are based on a work order's priority in accordance with AFR 85-2, shop hour availability, command interest, the date a work order becomes material complete, the date a work order was first requested, weather factors for outdoors work, and job-site availability.

Typically, there are many more work orders ready to be accomplished each month than there are labor hours available to accomplish them. This is where the IWP scheduler must make critical decisions, and thus, where an expert system could be beneficial.

Expert System Design

The goal of the expert system is to solidify certain criteria in order to provide relative weights for each work order, then to schedule each work order according to its weight and shop availability.

The expert system developed through this research effort was designed with the intent of providing a proof of concept that such a system could be used to help solve the IWP scheduling problem. The general system design is shown in Figure 7.

Although the expert system was developed using VP Expert and a database system on a PC, the resulting system should be readily transportable to the WIMS environment. The fields in the IWP Input database are in the WIMS IWP data file, and the majority of the fields in the Work Order Info database are in the WIMS Active Work Order data file. A field already exists in the Active Work Order data file for an IWP scheduled start date, and could be filled in by the IWP Scheduler Program. A WIMS report, or inquiry, to retrieve work order information based on the IWP start date could be written. The logic of the VP-Expert code for the scheduler itself could be coded fairly easily in COBOL, the language in which WIMS was developed.

The scheduler incorporates a multiplicative scoring technique derived from Captain Lillemon's additive model (13:121-125) and from the interview with Mr Foster. Weighting factors are assigned to specific work order

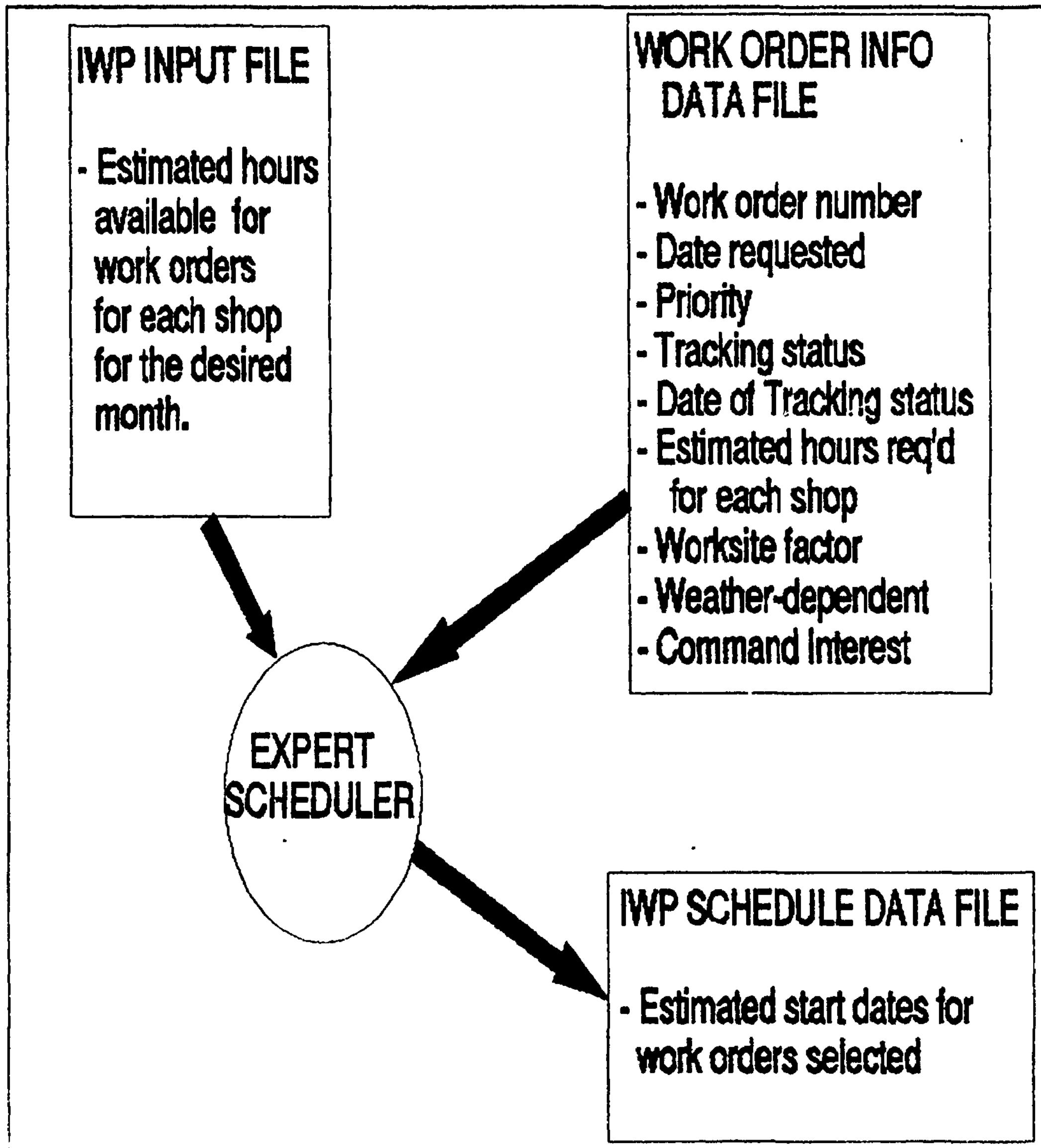

Figure 7 General System Design

criteria and multiplied together to produce a score for a particular work order. The scheduler program then schedules the work orders, those with the highest scores receiving highest priority, against available shop hours for the month for which we are trying to produce a schedule. If hours are not available for that month, the scheduler tries to fit it in the first future month, and then the second future month. If the scheduler is unable to schedule a work order for one of these three months, the work order will remain in the system for processing in later months.

The scoring equation is

$$S = PF * CIF * WF * FF * WSF * TISF * TMCF * BSF$$

where

S = Score

PF = Priority Factor

CIF = Command Interest Factor

WF = Weather Factor

FF = Fund Cite Factor

WSF = Work Site Availability Factor

TISF = Time-in-System Factor

TMCF = Time Material Complete Factor

and BSF = Bottleneck-Shop Factor.

The suggested multiplying factors for the possible values a weighting criteria may take are provided for each weighting criteria in Tables 2-9. These factors were used in the PC-based prototype, but should be modifiable in the WIMS-based version to allow managers at each installation to determine their own priorities. Setting values for these factors would be an important task for either a Civil Engineering or installation working group.

Table 2 shows the values associated with the work order priority, based on AFR 85-2. The values for these weights ensure that a Priority I work order will always have a higher total score than work orders with any other priority, a Priority II work order will almost always have a higher

TABLE 2

PRIORITY WEIGHTING FACTOR

PRIORITY	FACTOR
I	13
II	5
III	2
IV	1

score than Priority III and IV work orders, and Priority III work orders will generally have a higher score than Priority IV work orders.

TABLE 3

COMMAND INTEREST FACTOR

Command Interest?	Factor
Yes	1.6
No	1

The values for the Command Interest factor shown in Table 3 ensure that work orders with special status receive proper attention, but do not take precedence over mission critical or safety related work orders. A work order without command interest is not affected by this factor, therefore it has a multiplier of 1.

TABLE 4

WEATHER FACTOR

Is Weather a Factor?	Forecast	Factor
Yes	Good	2
Yes	Bad	0
No	Any	1

The Weather factor in Table 4 ensures that weather-dependent work orders, such as roofing and road work, are scheduled only during months when the forecast is good. This factor also ensures that such work receives high priority during the months that it can be scheduled. Work orders that are not weather-dependent receive Weather factor values of 1, and are therefore unaffected by weather.

The Worksite Availability factor shown in Table 5 ensures that a work order will not be scheduled if the job site is unavailable during a particular month. A value of 1 means the work order can be scheduled, a value of 0 ensures that it will not be scheduled.

TABLE 5

WORKSITE AVAILABILITY FACTOR

Worksite Available?	Factor
Yes	1
No	0

TABLE 6

FUND CITE FACTOR

Fundsite	Factor
Hospital	1.6
Housing	1.3
Mission Support Funds	1.4
O & M	1

Sometimes it is desirable to accomplish work orders from which the labor can be reimbursed with the customer organization's funds. This is especially true during times when O&M money is scarce and labor hours are abundant. As mentioned in Chapter 2, these separately-funded accounts include base medical centers, base housing, and special mission funds, such as the Airlift Support Industrial Fund for MAC units. At Dover, work orders with special fund cites were sometimes given higher priority than O&M work when funding was scarce. This ensured an even flow of work for craftsmen. The Fund Cite Factor in Table 6 accounts for this special funding by giving higher scores to reimbursable work orders.

The Time Material Complete (Table 7) and Time in System (Table 8) Factors give higher weights to those work orders that have been in the system longest. These two factors provide a degree of First-In-First-Out prioritization to the scheduling process to ensure fairness to customers.

TABLE 7

TIME MATERIAL COMPLETE FACTOR

Time Material Complete	Factor
Less than 1 year	1.0
Greater than 1 year	1.5

TABLE 8

TIME IN SYSTEM FACTOR

Years in System	Factor
0-1	1.0
1-2	1.2
2-3	1.4
>3	1.6

The final set of factors is the Bottleneck Shops Factor (Table 9), suggested in an interview with Lt Col Holt (3). Every CE squadron has at least one shop which is involved in most of the work orders, and whose manhours are therefore very valuable resources. Ensuring their hours are fully scheduled is critical. A situation should never occur where available bottleneck shop hours cannot be scheduled because less critical shops assigned to the work orders have no available hours. Therefore, work orders using bottleneck shops should be scheduled first. Once all bottleneck shop hours are used, work not requiring hours from the bottleneck shops can be scheduled against the less critical shops. The prototype system assumes that the carpenter and the interior electric shops are the bottleneck shops for this research.

TABLE 9

BOTTLENECK SHOPS FACTOR

Bottleneck Shops Scheduled	Factor
Interior Electric	1.5
Carpenter	1.5
Both	1.8
Neither	1.0

Expert System Prototype Implementation and Performance

System Implementation. The VP-Expert code listings are at Appendix E. VP-Expert is not intended for use as a programming tool with a great deal of control structure. Therefore, developing the system in a structured manner became tedious. The control flow of the system is shown in Figure 8.

The first action the program takes is to display an introduction to the user, explaining the system function. The system then prompts the user to input the month to be scheduled. This month becomes the "current month" to the system. The system then prompts the user to input the expected weather for the month. This input is used by the program to determine the Weather Factor for the score calculation.

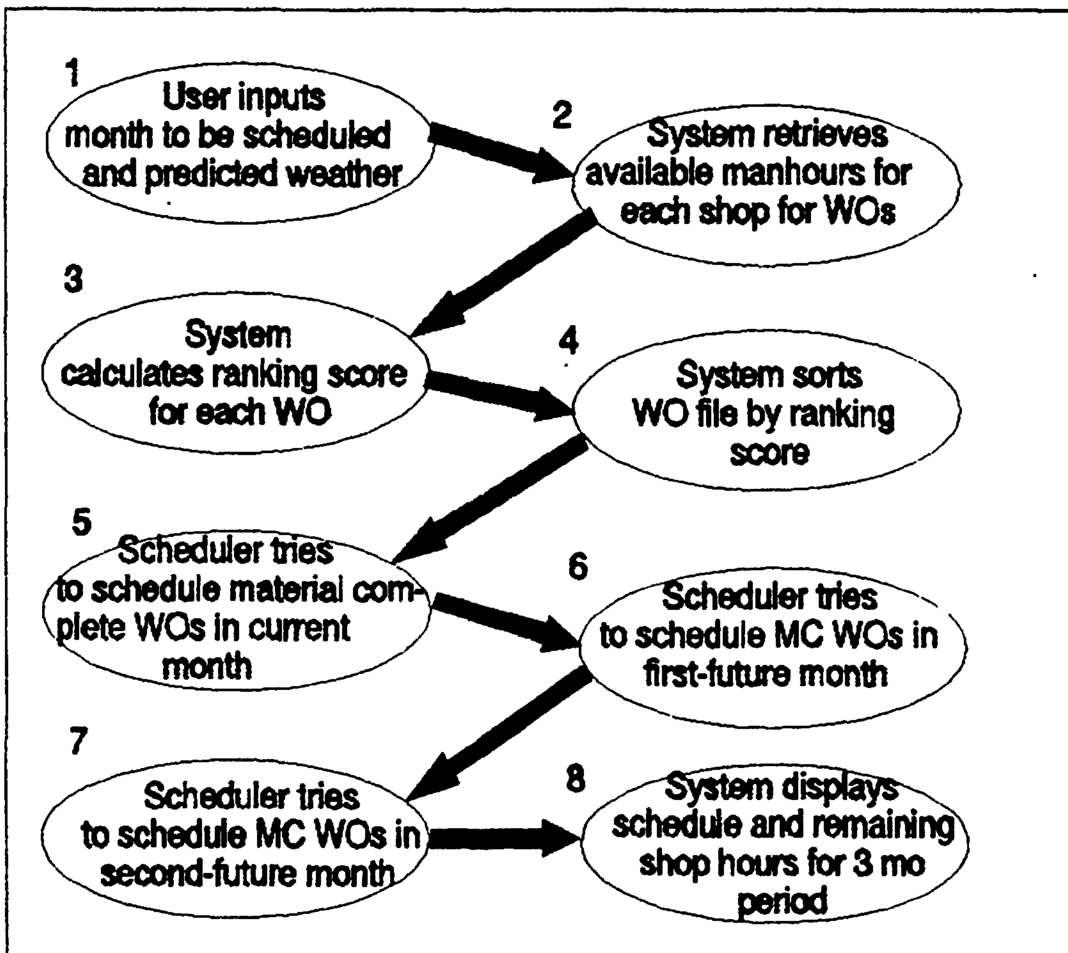

Figure 8 Control Flow of IWP Scheduler Program

Next, the system reads the database for the available manhours for each shop for the current month. These hours are displayed for the user to ensure accuracy. Step 3 involves reading all material complete work orders from the database and calculating a score for them based on the factors discussed above. The work orders are then sorted according to the score, with the work orders having the highest score listed first.

The system then reads each unscheduled work order, starting with the one with the highest score, to determine if it can be scheduled in the current month. If there are enough hours remaining for each shop to perform its required hours on the work order during the month, the current month is written to the IWP Scheduled Start Date field in the work order record. If it cannot be scheduled in the current month, a start date of 9999 is entered to signify that the work order has not yet been scheduled.

Once the system has attempted to schedule each work order in the current month, it tries to schedule all as yet unscheduled work orders in the first future month, following the same procedure described above. If a work order can be scheduled in the first future month, that date is written to the IWP Scheduled Start Date Field. The process is repeated for the second future month.

Next, the system displays the schedule to the user, indicating which work orders have been scheduled in the next three months. Finally, the system displays the unscheduled hours for each shop for each month. The IWP programmer can then use these hours for accomplishing more job orders, more recurring work, or starting work orders scheduled to begin the following month.

<u>Prototype Performance.</u> The VP-Expert prototype was tested using databases from the 2750th Civil Engineering Squadron at Wright-Patterson AFB. Information from the WIMS work order and labor availability databases was loaded into PC-based Paradox databases. Using an IBM 286 PC, the program generated a three-month schedule of 287 work orders in about 30 minutes. It took two IWP schedulers at Wright-Patterson one week each to build a one-month schedule from the same number of work orders. The printed schedule is at Appendix B. A listing of available hours for each shop for each of the three months is at Appendix C. A listing of remaining unscheduled hours for each shop is at Appendix D.

The test involved 287 work orders, of which five were priority 2, 275 were priority 3, and seven were priority 4. There were no priority 1 work orders in the test. The system scheduled four priority 2 work orders in the first month. The fifth priority 2 work order was scheduled in the second month. The priority 3 and 4 work orders were scheduled throughout the three month period. The system could not assign start dates for fourteen priority 3 and one priority 4 work orders, due to insufficient manhours remaining.

Of the 287 work orders used in the test, sixteen had command interest status. Of these sixteen work orders, the system scheduled nine in the first month, five in the second month, and two in the third. One command interest work order remained unscheduled.

Forty-nine of the tested work orders were dependent on good weather to be accomplished. The test assumed good weather for the three month scheduling period, and 43 of the 49 were scheduled. The system gave higher priority to scheduling older work orders when other factors were the same. This was expected with the use of the Time-in-System factor used by the program.

The interior electric and carpenter shops were used as the bottleneck shops during the test. The system ensured these shops were as fully scheduled as possible. This left no remaining hours available for the first month for either shop. The carpenter shop was fully scheduled for the second month as well, and had only one unscheduled hour for the third month. The interior electric shop had 30 remaining hours for the second month. The system was unable to schedule many work orders against the interior electric shop in the third month for two reasons. First, the material complete work orders that the interior electric shop could work on independently were all scheduled in the first and second months. Second, the remaining work orders requiring electrical manhours also required support from the carpenter shop, which was fully scheduled. This shows that the carpenter shop was the bottleneck shop for this quarter. The system will fully schedule whichever shop is the true bottleneck each quarter.

As a comparison, the Wright-Patterson AFB IWP programmer scheduled 195 work orders for the pericd of August and September. The expert system scheduled 193 work orders for the same period. Many, but not all, of the work orders were scheduled in the same month in both schedules. The automated system scheduled the shops tighter than the manual system, partly because the base IWP programmers chose to build flexibility into their schedule. The difference was especially apparent in the bottleneck shops, for which about 150-200 manhours were intentionally left unscheduled each month. These hours would be used during the month to accomplish insertions and work that went longer than planned. It took approximately four man-weeks to schedule August and September manually, while the expert system took thirty minutes to schedule August, September, and October.

Known Weaknesses. The expert system does possess three weaknesses, due in large part to the expert system shell used for the implementation. VP-Expert provides only very rudimentary program control features. Tasks such as data manipulation and looping, which are relatively easy to code in high order programming languages such as COBOL and Ada, are very cumbersome in VP-Expert.

The first major weakness caused by the difficulties in data handling was the inability to handle multi-month work orders. The system was unable to automatically spread manhours from large work orders over more than one month. If there were not enough hours available in a month for a shop to accomplish its portion of a work order, that work order would never be scheduled. This problem was overcome by creating additional work orders in the database to spread the hours over the necessary number of months. For example, if work order 73060 required 2000 carpenter hours and the shop averaged only 800 available manhours each month, new work orders 73061, 73062 and 73063 would be created. Each work order would contain the same scoring criteria as the original, and would require 500 carpenter hours to be accomplished. In this way, they could be scheduled individually over a four-month period. There were only two work orders used in the test which required this type of manipulation.

The second weakness, related to the first, was the inability of the system to move part of a work order up from month two to month one to take advantage of some of the remaining hours in month one. For example, if the plumbing shop had hours remaining for month one, an IWP programmer would look at the second month schedule for work orders the plumbing shop could begin working on early. The automated system was unable to do this.

The third major weakness of this expert system prototype is the inability to recalculate the weighting score for the second and third months of the schedule. The

Weather, Time-in-System, and Time-Material-Complete factors could all change as the month is incremented within the program, thus affecting the work order score. The benefits of adding a feature to recalculate these values for this prototype system were overshadowed by the tremendous amount of complexity which would be added. However, it should be noted that such a feature would be necessary in a complete implementation.

Summary of Prototype Performance. Overall, the expert system performed very well, ensuring the highest priority work was scheduled first and the shops were scheduled as near to capacity as possible. The program also produced this schedule quickly. It took the Wright-Patterson AFB IWP programmers about two man-weeks to develop a work plan for one month, while the expert system produced a three-month schedule in half an hour. The expert system built a very tight schedule which used as many available shop hours as possible. This should result in greater shop productivity. The system shortfall regarding dividing a work order over a period of several months was handled sufficiently using the technique mentioned above. One such work order was fully scheduled in the August-September time frame. The other had two of its four parts scheduled in September, one scheduled in October, and the other left unscheduled. The actual work orders in the manual system had hours scheduled against them in both August and September, but would require additional hours in the future months.

According to Mr Johnson, the system could be very effective at providing a good first cut at a three month schedule (16). Refinements to the schedule would probably be necessary as requirements and priorities changed, but the time saved in developing the first draft would be substantial.

V. Summary, Conclusions and Recommendations

Research Summary

The primary purpose of this research effort was to create an expert system for the IWP. In addition, the research was intended to prove that expert systems could be useful for aiding management decision-making in other areas of Civil Engineering.

Chapter II provided the foundation on which this study was built. Several previous AFIT students had demonstrated the need for expert systems in Civil Engineering, suggested some specific applications, and created some basic systems. Capt Lillemon developed a very useful analytical technique for assigning relative weights to work orders (13:32-36). Chapter III discussed the methodology used in conducting the research. Chapter IV discussed the results of the expert interviews, as well as the expert system prototype design and performance.

Conclusions

The expert IWP scheduler produced during this research is able to provide a three-month work plan in about 30 minutes. This is about 80 times faster than the current manual system, and frees the IWP schedulers to perform other work.

One of the most important contributions of this research was the implementation of a weighting technique to assign relative scores to individual work orders. A scoring technique is effective in ensuring that high priority work is accomplished. The weighting factors account for the many decision criteria an IWP programmer uses in assessing the relative merits of work orders to create a monthly schedule. As discussed in Chapter IV, these factors can be tailored, or even omitted, to meet local conditions.

Another contribution of the system is the ability to provide a three-month plan. A three-month schedule is important for providing such information as estimated start and completion dates to customers. A key reason why CE squadrons currently have a difficult time meeting commitments to customers is that requirements and priorities are constantly changing. New work orders with special "command interest" are often inserted into the schedule ahead of previously scheduled work. The automated three-month IWP schedule would quickly provide Civil Engineering and base managers the information required to make good decisions on the effects of these insertions. A new IWP could be created with the insertions to show exactly what work already scheduled would be sacrificed. The decision would then be made as to whether or not the new work is worth the disruption.

Another important benefit of the expert system is that it quickly creates a first draft schedule. The IWP programmer could then spend the time saved adjusting the schedule to meet new requirements and tracking work to ensure it is on schedule. For these reasons, an expert system for scheduling the Civil Engineering IWP seems to have great promise for increasing productivity and customer service.

<u>Recommendations</u>

This research has laid the foundation for several future projects and studies.

First, this prototype was only tested at one location. Testing of other CE databases is necessary to ensure that the system makes decisions like a true expert. It is possible that other weighting factors could be added, or that existing factors are not needed. In addition, further testing using differing values for the weighting factors should be conducted to determine if a set of "optimal" values exist. Such values would always produce the best schedule for the conditions.

The system developed during this study was only a prototype. Because it runs independently on a PC, it cannot access databases in the CE WIMS. Therefore, the second recommendation is to develop a full-scale implementation of the expert system that would use the existing WIMS data. CKI has developed an expert system shell for the Wang operating system. This shell, called Expert-R, could be used to develop the implementation, or the prototype can be implemented in COBOL, the language used to develop the WIMS applications.

Finally, more research could be conducted in other areas of Civil Engineering to determine if the application of expert systems would be useful and feasible.

Appendix A: Shop Labor Availability Form

FROM: IWP

SUBJECT: Man-hour Sheet for IWP Month (________________)

TO:

Number of Work Days: _________________ Cost Center: _________

1. a. Number of personnel assigned _________

   b. Number of personnel gains (hours) _________

   c. Number of personnel losses (hours) _________

2. a. Loans, borrowed, O.H., work-hours _________

   b. Loans (-) include cost center/hours _________

   c. Borrows (+) include from cost center/hours _________

3. Total estimated indirect hours _________

   a. LUC 31 (supervision) _________

   b. LUC 32 (training) _________

   c. LUC 33 (leave) _________

   d. LUC 34 (other - specify, i.e. comp time, shop and vehicle cleanup, etc) _________

   ____

   ____

4. Estimated Prime BEEF training hours _________

   Comments: ____

   ____

   ____

   Foreman's Initials _________ Superintendent ___________

Appendix B: System-Produced IWP Schedule

The IWP Schedule for August 1991 is:

WO Number	IWP Start		CI	Weather	Date In		Priority	Score
70494	91	8	y	y	89	2	3	15.3
78373	91	8	n	n	91	1	2	14.4
70387	91	8	n	n	89	1	2	12.0
70731	91	8	n	n	89	2	2	12.0
79217	91	8	n	n	91	3	2	12.0
69734	91	8	n	y	88	11	3	11.5
70173	91	8	n	y	88	12	3	11.5
71861	91	8	n	y	89	5	3	11.5
71930	91	8	n	y	89	5	3	11.5
77763	91	8	n	y	90	10	3	11.5
80024	91	8	y	y	91	6	3	10.2
71695	91	8	n	y	89	5	3	9.6
77096	91	8	n	y	90	8	3	9.6
73080	91	8	y	n	89	9	3	9.2
77443	91	8	y	n	90	9	3	9.2
79281	91	8	y	n	91	7	3	7.6
79406	91	8	y	n	91	4	3	7.6
80343	91	8	y	n	91	7	3	7.6
75661	91	8	n	y	90	3	3	6.4
76895	91	8	n	y	90	7	3	6.4
76896	91	8	n	y	90	7	3	6.4
76898	91	8	n	y	90	7	3	6.4
78350	91	8	n	y	91	1	3	6.4
78351	91	8	n	y	91	1	3	6.4
80420	91	8	n	y	91	7	3	6.4
69231	91	8	n	n	88	10	3	5.7
76797	91	8	n	n	90	7	3	5.7
80365	91	8	n	n	91	7	3	5.7
76991	91	8	y	n	90	8	3	5.1
78977	91	8	y	n	91	3	3	5.1
68224	91	8	n	n	88	6	3	4.8
68325	91	8	n	n	88	7	3	4.8
69464	91	8	n	n	88	10	3	4.8
70147	91	8	n	n	88	12	3	4.8
70574	91	8	n	n	89	2	3	4.8
70899	91	8	n	n	89	3	3	4.8
72839	91	8	n	n	89	8	3	4.8
72886	91	8	n	n	89	8	3	4.8
73009	91	8	n	n	89	8	3	4.8
73050	91	8	n	n	89	9	3	4.8
73181	91	8	n	n	89	9	3	4.8
73565	91	8	n	n	89	10	3	4.8
73775	91	8	n	n	89	10	3	4.8

77760	91	8	n	n	90	10	3	4.8
77814	91	8	n	n	90	10	3	[illegible]
70526	91	8	n	n	89	2	3	3.2
72358	91	8	n	n	89	7	3	3.2
73285	91	8	n	n	89	9	3	3.2
7230[illegible]	91	8	n	n	89	9	3	3.2
73405	91	8	n	n	89	9	3	3.2
73437	91	8	n	n	89	9	3	3.2
73779	91	8	n	n	89	10	3	3.2
73869	91	8	n	n	89	10	[illegible]	[illegible]
74191	91	8	n	n	89	11	[illegible]	[illegible]
74307	91	8	n	n	89	11	[illegible]	[illegible]
7515[illegible]	91	8	n	n	90	2	[illegible]	[illegible]
75705	91	8	[illegible]	[illegible]	90	[illegible]	[illegible]	[illegible]
75708	91	8	n	n	90	3	[illegible]	[illegible]
75962	91	8	n	[illegible]	90	4	[illegible]	[illegible]
76552	91	8	n	n	90	6	[illegible]	[illegible]
76974	91	8	n	n	90	7	[illegible]	3.2
77060	91	8	n	n	90	8	[illegible]	[illegible]
77146	91	8	n	n	90	8	[illegible]	[illegible]
77462	91	8	n	n	90	9	[illegible]	[illegible]
78415	91	8	n	n	91	1	[illegible]	[illegible]
78503	91	8	n	n	91	1	[illegible]	[illegible]
78681	91	8	n	n	91	2	[illegible]	[illegible]
79032	91	8	n	n	91	3	[illegible]	[illegible]
79626	91	8	n	n	91	4	[illegible]	[illegible]
79736	91	8	n	n	91	5	[illegible]	[illegible]
79798	91	8	n	n	91	5	[illegible]	[illegible]
79800	91	8	n	n	91	5	[illegible]	[illegible]
80112	91	8	n	n	91	6	[illegible]	[illegible]
79419	91	8	n	n	91	4	[illegible]	[illegible]
80252	91	8	n	n	91	6	[illegible]	[illegible]
80505	91	8	n	n	91	7	4	[illegible]

The IWP Schedule for September 1991 is:

WO Number	IWP Start		CI	Weather	Date In		Priority	Score
71942	91	9	n	y	89	5	3	11.5
72547	91	9	n	y	89	7	3	11.5
70996	91	9	n	y	89	3	3	9.6
72041	91	9	n	y	89	6	3	9.6
73964	91	9	n	y	89	10	3	9.6
76423	91	9	n	y	90	5	3	9.6
77665	91	9	n	y	90	10	3	9.6
73061	91	9	y	n	89	9	3	9.2
73063	91	9	y	n	89	9	3	9.2
75759	91	9	y	n	90	3	3	9.2
80029	91	9	y	n	91	6	3	9.2
79968	91	9	n	n	91	5	2	8.0
74915	91	9	y	n	90	1	3	7.6
71217	91	9	n	y	89	4	3	6.4
76636	91	9	n	y	90	6	3	6.4
76899	91	9	n	y	90	7	3	6.4
77359	91	9	n	y	90	9	3	6.4
77361	91	9	n	y	90	9	3	6.4
80410	91	9	n	y	91	7	3	6.4
68725	91	9	n	n	88	8	3	5.7
70098	91	9	n	n	88	12	3	5.7
70437	91	9	n	n	89	1	3	5.7
71520	91	9	n	n	89	4	3	5.7
73517	91	9	n	n	89	10	3	5.7
74230	91	9	n	n	89	11	3	5.7
74354	91	9	n	n	89	11	3	5.7
74544	91	9	n	n	89	12	3	5.7
75778	91	9	n	n	90	3	3	5.7
76919	91	9	n	n	90	7	3	5.7
71343	91	9	n	n	89	4	3	4.8
73271	91	9	n	n	89	9	3	4.8
73397	91	9	n	n	89	9	3	4.8
73469	91	9	n	n	89	9	3	4.8
73603	91	9	n	n	89	10	3	4.8
73774	91	9	n	n	89	10	3	4.8
73918	91	9	n	n	89	10	3	4.8
74110	91	9	n	n	89	11	3	4.8
74176	91	9	n	n	89	11	3	4.8
74231	91	9	n	n	89	11	3	4.8
74289	91	9	n	n	89	11	3	4.8
74589	91	9	n	n	89	12	3	4.8
74688	91	9	n	n	89	12	3	4.8
74826	91	9	n	n	90	1	3	4.8
74891	91	9	n	n	90	1	3	4.8
74968	91	9	n	n	90	1	3	4.8
75054	91	9	n	n	90	1	3	4.8

75362	91	9	n	n	90	2	3	4.8
75508	91	9	n	n	90	3	3	4.8
75808	91	9	n	n	90	4	3	4.8
75866	91	9	n	n	90	4	3	4.8
76154	91	9	n	n	90	5	3	4.8
76203	91	9	n	n	90	5	3	4.8
76329	91	9	n	n	90	5	3	4.8
76386	91	9	n	n	90	5	3	4.8
76399	91	9	n	n	90	5	3	4.8
76724	91	9	n	n	90	7	3	4.8
76818	91	9	n	n	90	7	3	4.8
76832	91	9	n	n	90	7	3	4.8
76833	91	9	n	n	90	7	3	4.8
76943	91	9	n	n	90	7	3	4.8
77333	91	9	n	n	90	9	3	4.8
77566	91	9	n	n	90	9	3	4.8
77579	91	9	n	n	90	9	3	4.8
77630	91	9	n	n	90	10	3	4.8
77724	91	9	n	n	90	10	3	4.8
77850	91	9	n	n	90	10	3	4.8
78232	91	9	n	n	90	12	3	4.8
78234	91	9	n	n	90	12	3	4.8
78267	91	9	n	n	90	12	3	4.8
78342	91	9	n	n	91	1	3	4.8
78496	91	9	n	n	91	1	3	4.8
78601	91	9	n	n	91	1	3	4.8
78692	91	9	n	n	91	2	3	4.8
78705	91	9	n	n	91	2	3	4.8
78923	91	9	n	n	91	2	3	4.8
79016	91	9	n	n	91	3	3	4.8
79166	91	9	n	n	91	3	3	4.8
79307	91	9	n	n	91	4	3	4.8
79364	91	9	n	n	91	4	3	4.8
79367	91	9	n	n	91	4	3	4.8
79371	91	9	n	n	91	4	3	4.8
79549	91	9	n	n	91	4	3	4.8
79598	91	9	n	n	91	4	3	4.8
79729	91	9	n	n	91	5	3	4.8
79786	91	9	n	n	91	5	3	4.8
68233	91	9	n	n	88	6	3	3.2
69192	91	9	n	n	88	9	3	3.2
73307	91	9	n	n	89	9	3	3.2
74381	91	9	n	n	89	11	3	3.2
74475	91	9	n	n	89	11	3	3.2
74784	91	9	n	y	89	12	4	3.2
75034	91	9	n	n	90	1	3	3.2
75920	91	9	n	n	90	4	3	3.2
76101	91	9	n	n	90	4	3	3.2
76512	91	9	n	n	90	6	3	3.2
76706	91	9	n	n	90	7	3	3.2
77152	91	9	n	n	90	8	3	3.2

77410	91	9	n	n	90	9	3	3.2
77416	91	9	n	n	90	9	3	3.2
77450	91	9	n	n	90	9	3	3.2
77706	91	9	n	n	90	10	3	3.2
78203	91	9	n	n	90	12	3	3.2
78417	91	9	n	n	91	1	3	3.2
78418	91	9	n	n	91	1	3	3.2
78420	91	9	n	n	91	1	3	3.2
78498	91	9	n	n	91	1	3	3.2
78514	91	9	n	n	91	1	3	3.2
78518	91	9	n	n	91	1	3	3.2
78519	91	9	n	n	91	1	3	3.2
78520	91	9	n	n	91	1	3	3.2
79036	91	9	n	n	91	3	3	3.2
79037	91	9	n	n	91	3	3	3.2
79145	91	9	n	n	91	3	3	3.2
79426	91	9	n	n	91	4	3	3.2
79506	91	9	n	n	91	4	3	3.2
79972	91	9	n	n	91	5	3	3.2
80444	91	9	n	n	91	7	4	2.4

The IWP Schedule for October 1991 is:

WO Number	IWP Start	CI	Weather	Date In	Priority	Score
72802	91 10	n	y	89 8	3	9.6
73062	91 10	y	n	89 9	3	9.2
76738	91 10	y	n	90 7	3	7.6
71795	91 10	n	y	89 5	3	6.4
71909	91 10	n	y	89 5	3	6.4
72437	91 10	n	y	89 7	3	6.4
73862	91 10	n	y	89 10	3	6.4
74082	91 10	n	y	89 11	3	6.4
74659	91 10	n	y	89 12	3	6.4
77360	91 10	n	y	90 9	3	6.4
77362	91 10	n	y	90 9	3	6.4
77364	91 10	n	y	90 9	3	6.4
77705	91 10	n	y	90 10	3	6.4
79887	91 10	n	y	91 5	3	6.4
70053	91 10	n	n	88 12	3	5.7
71259	91 10	n	n	89 4	3	5.7
71924	91 10	n	n	89 5	3	5.7
71943	91 10	n	n	89 5	3	5.7
72635	91 10	n	n	89 8	3	5.7
72644	91 10	n	n	89 8	3	5.7
72648	91 10	n	n	89 8	3	5.7
72753	91 10	n	n	89 8	3	5.7
73242	91 10	n	n	89 9	3	5.7
73624	91 10	n	n	89 10	3	5.7
73647	91 10	n	n	89 10	3	5.7
73776	91 10	n	n	89 10	3	5.7
73890	91 10	n	y	89 10	4	5.7
73944	91 10	n	n	89 10	3	5.7
75984	91 10	n	n	90 4	3	5.7
76515	91 10	n	n	90 6	3	5.7
76944	91 10	n	n	90 7	3	5.7
77108	91 10	n	n	90 8	3	5.7
77449	91 10	n	n	90 9	3	5.7
78066	91 10	n	n	90 11	3	5.7
78081	91 10	n	n	90 11	3	5.7
78122	91 10	n	n	90 12	3	5.7
78332	91 10	n	n	90 12	3	5.7
78584	91 10	n	n	91 1	3	5.7
78586	91 10	n	n	91 1	3	5.7
78622	91 10	n	n	91 1	3	5.7
78798	91 10	n	n	91 2	3	5.7
78833	91 10	n	n	91 2	3	5.7
78886	91 10	n	n	91 2	3	5.7
78887	91 10	n	n	91 2	3	5.7
78971	91 10	n	n	91 3	3	5.7
79249	91 10	n	n	91 3	3	5.7
79636	91 10	n	n	91 4	3	5.7

80217	91 10	n	n	91 6	3	5.7
68196	91 10	n	n	88 6	3	4.8
68474	91 10	n	n	88 7	3	4.8
68552	91 10	n	n	88 7	3	4.8
68600	91 10	n	n	88 8	3	4.8
70223	91 10	n	n	89 1	3	4.8
71047	91 10	n	n	89 3	3	4.8
71203	91 10	n	n	89 4	3	4.8
71408	91 10	n	n	89 4	3	4.8
71725	91 10	n	n	89 5	3	4.8
72525	91 10	n	n	89 7	3	4.8
73343	91 10	n	n	89 9	3	4.8
77057	91 10	n	n	90 8	3	4.8
79132	91 10	n	n	91 3	3	4.8
79176	91 10	n	n	91 3	3	4.8
79290	91 10	n	n	91 4	3	4.8
79338	91 10	n	n	91 4	3	4.8
79625	91 10	n	n	91 4	3	4.8
79795	91 10	n	n	91 5	3	4.8
79927	91 10	n	n	91 5	3	4.8
69882	91 10	n	n	88 11	3	3.2
70952	91 10	n	n	89 3	3	3.2
71688	91 10	n	n	89 5	3	3.2
73033	91 10	n	n	89 9	3	3.2
73572	91 10	n	n	89 10	3	3.2
73778	91 10	n	n	89 10	3	3.2
74357	91 10	n	n	89 11	3	3.2
75208	91 10	n	n	90 2	3	3.2
75554	91 10	n	n	90 3	3	3.2
77058	91 10	n	n	90 8	3	3.2
78515	91 10	n	n	91 1	3	3.2
79038	91 10	n	n	91 3	3	3.2

The Unscheduled Work Orders for this run are:

WO Number	IWP Start	CI	Weather	Date In	Priority	Score
78353	99 99	n	y	91 1	3	11.5
78354	99 99	n	y	91 1	3	9.6
73060	99 99	y	n	89 9	3	9.2
78170	99 99	n	y	90 12	3	6.4
78171	99 99	n	y	90 12	3	6.4
78226	99 99	n	y	90 12	3	6.4
78329	99 99	n	y	90 12	3	6.4
75540	99 99	n	n	90 3	3	5.7
79357	99 99	n	n	91 4	3	5.7
71142	99 99	n	n	89 3	3	4.8
72857	99 99	n	n	89 8	3	4.8
75900	99 99	n	n	90 4	3	4.8
77745	99 99	n	n	90 10	3	4.8
78355	99 99	n	n	91 1	3	4.8
79878	99 99	n	n	91 5	4	1.6

Appendix C: Test Case Shop Availability

The available hours for the shops for August 91 are:

Shop 433	=	266.0
Shop 441	=	1632.0
Shop 443	=	1264.0
Shop 451	=	1829.0
Shop 452	=	1184.0
Shop 453	=	508.0
Shop 454	=	1613.0
Shop 456	=	159.0
Shop 457	=	1407.0
Shop 461	=	93.0
Shop 462	=	271.0
Shop 463	=	1261.0
Shop 464	=	438.0
Shop 465	=	2003.0
Shop 468	=	23.0
Shop 469	=	295.0
Shop 471	=	1993.0
Shop 472	=	399.0
Shop 480	=	92.0
Shop 493	=	118.0

The available hours for the shops for September 1991 are:

Shop 433	=	63.0
Shop 441	=	1066.0
Shop 443	=	221.0
Shop 451	=	2594.0
Shop 452	=	1050.0
Shop 453	=	501.0
Shop 454	=	1409.0
Shop 456	=	14.0
Shop 457	=	14.0
Shop 461	=	235.0
Shop 462	=	336.0
Shop 463	=	147.0
Shop 464	=	353.0
Shop 465	=	2132.0
Shop 468	=	64.0
Shop 469	=	194.0
Shop 471	=	1799.0
Shop 472	=	643.0
Shop 480	=	200.0
Shop 493	=	48.0

The available hours for the shops for October 1991 are:

Shop 433	=	63.0
Shop 441	=	1066.0
Shop 443	=	221.0
Shop 451	=	2594.0
Shop 452	=	1050.0
Shop 453	=	501.0
Shop 454	=	1409.0
Shop 456	=	14.0
Shop 457	=	14.0
Shop 461	=	232.0
Shop 462	=	336.0
Shop 463	=	147.0
Shop 464	=	353.0
Shop 465	=	2132.0
Shop 468	=	64.0
Shop 469	=	194.0
Shop 471	=	1800.0
Shop 472	=	643.0
Shop 480	=	200.0
Shop 493	=	48.0

Appendix D: Test Case Shop Remaining Hours

The remaining hours for each shop for these months are

Shop	August	September	October
433	17[illegible]	63	6[illegible]
441	2	4	20
442	142	5	[illegible]
451	0	0	[illegible]
452	[illegible]	200	4[illegible]
453	11	29	[illegible]
454	1[illegible]	10[illegible]	1[illegible]
456	79	1[illegible]	1[illegible]
457	[illegible]	1[illegible]	[illegible]
461	29	[illegible]	[illegible]
462	191	56	[illegible]
463	12	2	1[illegible]
464	30	47	[illegible]
465	95	6	[illegible]
468	15	44	40
469	279	78	1[illegible]
471	0	[illegible]	22[illegible]
472	315	121	513
480	92	200	192
493	118	48	[illegible]

Appendix E: VP-Expert Program Listing

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                                           !
!                                  Phillip W. Melancon      !
!                                  AFIT/GSS/DEV/91D-10      !
!                                  December 1991            !
!                                                           !
!        An Epxert System for the Civil                     !
!       Engineering In-Service Work Plan                    !
!                Version 1.0                                !
!                                                           !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                                           !
!  This program reads in work order data from a database    !
!  file, assigns a ranking score to each work order, and    !
!  schedules the work orders according to their score.  A   !
!  three-month schedule is then displayed for the user.     !
!  This version uses all CE shops.  Interactive windows are !
!  used to explain each step in the process.                !
!                                                           !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

! Actions Block

ENDOFF;
RUNTIME;
BKCOLOR=1;
ACTIONS

!  This first block of statements inputs a text file for the
!  intro screen.

COLOR=7
WHILEKNOWN introtext
  RECEIVE iwptext,introtext
  DISPLAY "{introtext}"
END

DISPLAY "Press any key to continue~"
CLS
```

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                                         !
! This section pulls relevant data from the data file     !
! containing the current IWP date and the corresponding   !
! available hours for each shop for the month, the        !
! IWPSHOPS.DBF file.  First the user is queried for the   !
! desired month to schedule.  The input data is then      !
! displayed to the user.                                  !
!                                                         !

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

WOPEN 1,1,5,19,70,4
  ACTIVE 1
  DISPLAY
  "      This first screen prompts you for your input.
  You will first be asked to input the year and month
  for the schedule you will be working on.  Use the
  format provided for your response.

  Next you will be asked for the anticipated weather for
  the month.  This will tell the system whether or not
  outdoor work, such as roadwork and roofing, should be
  scheduled this month.  Your choices are 'Good' and 'Bad.'
  Typically, April through October should have 'Good'
  weather, November through March should have 'Bad.'

  Press any key to continue~"

WCLOSE 1

Color=7
FIND Current_Year
FIND Current_Month
This_Year = (Current_Year)
This_Month = (Current_Month)

GET Current_Month=IWP_Month AND Current_Year=
                                  IWP_Year,iwpshops,all
cls

WOPEN 2,5,5,10,70,4
   ACTIVE 2
   DISPLAY
  "      This screen displays the number of available hours each
  shop has for work orders.  These hours are retrieved from the
  IWPSHOPS database.  Please ensure the hours are within reason
  and correct any errors you find in the database.

  Press any key to continue~"

WCLOSE 2
COLOR=7
```

```
DISPLAY "The available hours for the shops this month are:"
DISPLAY " "
DISPLAY "          Shop 433  =  {shop433hrs}
          Shop 441  =  {shop441hrs}
          Shop 443  =  {shop443hrs}
          Shop 451  =  {shop451hrs}
          Shop 452  =  {shop452hrs}
          Shop 453  =  {shop453hrs}
          Shop 454  =  {shop454hrs}
          Shop 456  =  {shop456hrs}
          Shop 457  =  {shop457hrs}
          Shop 461  =  {shop461hrs}
          Shop 462  =  {shop462hrs}
          Shop 463  =  {shop463hrs}
          Shop 464  =  {shop464hrs}
          Shop 465  =  {shop465hrs}
          Shop 468  =  {shop468hrs}
          Shop 469  =  {shop469hrs}
          Shop 471  =  {shop471hrs}
          Shop 472  =  {shop472hrs}
          Shop 480  =  {shop480hrs}
          Shop 493  =  {shop493hrs}"

DISPLAY " "
DISPLAY "The system will now calculate weighting factors"
DISPLAY "and ranking scores for each work order.  Please"
DISPLAY "be patient while I crunch these numbers."
DISPLAY " "
DISPLAY "Press any key to continue~"
CLS

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                                     !
! This section retrieves the work order data from     !
! the data base for all material complete work orders, !
! and assigns them a ranking score.                   !
!                                                     !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

  Desired_status = mc
  WHILEKNOWN Wonumber

    RESET new_score
    RESET score
    RESET Priority_Factor
    RESET Command_Factor
    RESET Weather_Factor
    RESET Fundsite_Factor
    RESET Status_Factor
    RESET Worksite_Factor
    RESET Time_Material_Complete_Factor
    RESET Time_in_System_Factor
    RESET Bottleneck_Shops_Factor
```

```
        Get Desired_status=status,iwpwork,all
        FIND Priority_Factor
        FIND Command_Factor
        FIND Weather_Factor
        FIND Fundsite_Factor
        FIND Status_Factor
        FIND Worksite_Factor
          Months_in_System_Difference =
                                   (This_Month - Month_in_System)
          Stat_Month_Difference = (This_Month - Stat_Month)
        FIND Time_Material_Complete_Factor
        FIND Time_in_System_Factor
        FIND Bottleneck_Shops_Factor
        score1 = (priority_factor * command_factor
                  * weather_factor)
        score2 = (score1 * fundsite_factor * status_factor
                  * worksite_factor)
        score  = (score2 * Time_in_System_Factor *
                              Time_Material_Complete_Factor *
                  Bottleneck_Shops_Factor)
        FORMAT score,4.1
        PUT iwpwork
        END
        CLOSE iwpwork

  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
  !                                                  !
  !  This section displays the sorted data base      !
  !  by the ranking score.                           !
  !                                                  !
  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

  WOPEN 4,5,5,10,65,4
    ACTIVE 4
    DISPLAY
    "     The next screen displays all material complete
     work orders sorted by their ranking score.  This is
     the order in which work orders shall be scheduled.

     Press any key to continue~"
  WCLOSE 4
  COLOR=7

        DISPLAY
        "The material complete work orders sorted by rank are:"
        DISPLAY " "
        DISPLAY  " wonumber       priority      command interest
                   ranking score    Status Date"
        DISPLAY
        "------------------------------------------------------"
        WHILEKNOWN wonumber
        GET ALL,iwpsort,all
        FORMAT score,4.1
```

```
     FORMAT stat_year,2.0
     FORMAT stat_month,2.0
     DISPLAY " {number}        {priority}    ^G{comintrst}
              {score}           {Stat_Year}{Stat_Month}"
     END
     DISPLAY "Press any key to continue.~"
     cls
     CLOSE iwpsort

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                                          !
!  This section retrieves each work order from             !
!  the sorted database and assigns an IWP schedule         !
!  date.  The schedule is then displayed for the           !
!  user. In addition, any remaining hours for the          !
!  shops are displayed for the user for further            !
!  schedule adjustments.                                   !
!                                                          !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

     shop433_remaining_hours = (shop433hrs)
     shop441_remaining_hours = (shop441hrs)
     shop443_remaining_hours = (shop443hrs)
     shop451_remaining_hours = (shop451hrs)
     shop452_remaining_hours = (shop452hrs)
     shop453_remaining_hours = (shop453hrs)
     shop454_remaining_hours = (shop454hrs)
     shop456_remaining_hours = (shop456hrs)
     shop457_remaining_hours = (shop457hrs)
     shop461_remaining_hours = (shop461hrs)
     shop462_remaining_hours = (shop462hrs)
     shop463_remaining_hours = (shop463hrs)
     shop464_remaining_hours = (shop464hrs)
     shop465_remaining_hours = (shop465hrs)
     shop468_remaining_hours = (shop468hrs)
     shop469_remaining_hours = (shop469hrs)
     shop471_remaining_hours = (shop471hrs)
     shop472_remaining_hours = (shop472hrs)
     shop480_remaining_hours = (shop480hrs)
     shop493_remaining_hours = (shop493hrs)

WOPEN 5,2,5,17,65,4
  ACTIVE 5
  DISPLAY
  "   The system will now retrieve and display available shop
   hours for the first and second future months.  It will also
   develop a schedule for the three month period.  During these
   calculations, the screen will appear to break off.  Don't
   worry - I am just chaining to another expert system.  Please
   be patient as these operations take some time!
      The system first tries to schedule work in the current
   month.   After using all the shop hours available in the
```

```
   current, the system will try to schedule work orders in the
   next month, then the next.  If a work order cannot be
   scheduled in one of the three months, a start date of 9999
   is assigned to show a far off month.

   Press any key to continue  ~"

DISPLAY "      The remaining hours for each shop are listed
   on the final screen.  Although there are not enough hours
   remaining to complete any additional work orders, these
   hours can be used to start new work at the end of the month,
   or do additional job orders or recurring work.

   Press any key to continue~"
WCLOSE 5
COLOR=7

       WHILEKNOWN Wonumber
          GET ALL,iwpsort,all

             RESET IWP_Month
             RESET IWP_Year
             FIND IWP_Month
             FIND IWP_Year
             PUT iwpsort

      END

SAVEFACTS c:\vpxp\iwptemp
CHAIN iwpchain
;

! Rules Block

RULE 1
IF    Priority = 1
THEN  Priority_Factor = 13;

RULE 2
IF    Priority = 2
THEN  Priority_Factor = 5;

RULE 3
IF    Priority = 3
THEN  Priority_Factor = 2;

RULE 4
IF    Priority = 4
THEN  Priority_Factor = 1;
```

```
RULE 5
IF    Comintrst = y
THEN  Command_Factor = 1.6
ELSE  Command_Factor = 1.0;

RULE 6
IF    Weather = n
THEN  Weather_Factor = 1;

RULE 7
IF    Weather = y
AND   Conditions = Good
THEN  Weather_Factor = 2;

RULE 8
IF    Weather = y
AND   Conditions = Bad
THEN  Weather_Factor = 0 CNF 80;

RULE 9
IF    Fundsite = 1
THEN  Fundsite_Factor = 1.6;

RULE 10
IF    Fundsite = 2
THEN  Fundsite_Factor = 1.3;

RULE 11
IF    Fundsite = 3
THEN  Fundsite_Factor = 1.4;

RULE 12
IF    Fundsite = 4
THEN  Fundsite_Factor = 1;

RULE 13
IF    Status = mc
THEN  Status_Factor = 1 CNF 90
ELSE  Status_Factor = 0 CNF 100;

RULE 14
IF    Worksite = y
THEN  Worksite_Factor = 1
ELSE  Worksite_Factor = 0;

RULE 15
IF    Months_in_System_Difference  >= 0
THEN  Years_in_System = (This_Year - Year_in_System)
ELSE  Years_in_System = (This_Year - Year_In_System - 1);
```

```
RULE 16
IF    Stat_Month_Difference >= 0
THEN  Time_Material_Complete = (This_Year - Stat_Year)
ELSE  Time_Material_Complete = (This_Year - Stat_Year - 1);

RULE 17
IF    Time_Material_Complete >= 1
THEN  Time_Material_Complete_Factor = 1.7
ELSE  Time_Material_Complete_Factor = 1;

RULE 18
IF    Years_in_System = 0
THEN  Time_in_Sytsem_Factor = 1;

RULE 19
IF    Years_in_System = 1
THEN  Time_in_System_Factor = 1.2;

RULE 20
IF    Years_in_System = 2
THEN  Time_in_System_Factor = 1.4;

RULE 21
IF    Years_in_System >= 3
THEN  Time_in_System_Factor = 1.6;

RULE 22
IF Shop451 > 0 AND Shop471 > 0
THEN Bottleneck_Shops_Factor = 1.8;

RULE 23
IF Shop451 > 0 OR Shop471 > 0
THEN Bottleneck_Shops_Factor = 1.5
ELSE Bottleneck_Shops_Factor = 1.0;

RULE 24
IF  shop433 <= (shop433_remaining_hours)
AND shop441 <= (shop441_remaining_hours)
AND shop443 <= (shop443_remaining_hours)
AND shop451 <= (shop451_remaining_hours)
AND shop452 <= (shop452_remaining_hours)
AND shop453 <= (shop453_remaining_hours)
AND shop454 <= (shop454_remaining_hours)
AND shop456 <= (shop456_remaining_hours)
AND shop457 <= (shop457_remaining_hours)
AND shop461 <= (shop461_remaining_hours)
AND shop462 <= (shop462_remaining_hours)
AND shop463 <= (shop463_remaining_hours)
AND shop464 <= (shop464_remaining_hours)
AND shop465 <= (shop465_remaining_hours)
AND shop468 <= (shop468_remaining_hours)
AND shop469 <= (shop469_remaining_hours)
AND shop471 <= (shop471_remaining_hours)
```

```
AND shop472 <= (shop472_remaining_hours)
AND shop480 <= (shop480_remaining_hours)
AND shop493 <= (shop493_remaining_hours)

THEN IWP_Month = (This_Month)
     IWP_Year  = (This_Year)
     shop433_remaining_hours = (shop433_remaining_hours - shop433)
     shop441_remaining_hours = (shop441_remaining_hours - shop441)
     shop443_remaining_hours = (shop443_remaining_hours - shop443)
     shop451_remaining_hours = (shop451_remaining_hours - shop451)
     shop452_remaining_hours = (shop452_remaining_hours - shop452)
     shop453_remaining_hours = (shop453_remaining_hours - shop453)
     shop454_remaining_hours = (shop454_remaining_hours - shop454)
     shop456_remaining_hours = (shop456_remaining_hours - shop456)
     shop457_remaining_hours = (shop457_remaining_hours - shop457)
     shop461_remaining_hours = (shop461_remaining_hours - shop461)
     shop462_remaining_hours = (shop462_remaining_hours - shop462)
     shop463_remaining_hours = (shop463_remaining_hours - shop463)
     shop464_remaining_hours = (shop464_remaining_hours - shop464)
     shop465_remaining_hours = (shop465_remaining_hours - shop465)
     shop468_remaining_hours = (shop468_remaining_hours - shop468)
     shop469_remaining_hours = (shop469_remaining_hours - shop469)
     shop471_remaining_hours = (shop471_remaining_hours - shop471)
     shop472_remaining_hours = (shop472_remaining_hours - shop472)
     shop480_remaining_hours = (shop480_remaining_hours - shop480)
     shop493_remaining_hours = (shop493_remaining_hours - shop493)

ELSE IWP_Month = 99
     IWP_Year = 99;

RULE 25
IF This_Month < 12
THEN First_Future_Month = (This_Month + 01)
     Year_of_First_Future_Month = (This_Year)
ELSE First_Future_Month = 01
     Year_of_First_Future_Month = (This_Year + 01);

RULE 26
IF First_Future_Month < 12
THEN Second_Future_Month = (First_Future_Month + 01)
     Year_of_Second_Future_Month = (Year_of_First_Future_Month)
ELSE Second_Future_Month = 01
     Year_of_Second_Future_Month = (Year_of_First_Future_Month + 01);

!Statements Block

ASK Current_Year: "What is the IWP year you would like to create?
(Please express as two-digit year, i.e. 1991 = 91)";
ASK Current_Month: "What is the IWP month you would like to create?
(Please express as digits, i.e. January = 1, December = 12)";

ASK Conditions: "What is the weather outlook for the month?";
CHOICES Conditions: Good,Bad;
```

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                                                !
!                          IWPCHAIN                              !
!                                                                !
!  This is a separate program called by IWPEXP.  Due to memory   !
!  constraints of VP-Expert, not all code could be contained in  !
!  the first program.  The link between the two programs is      !
!  transparent to the user.                                      !
!                                                                !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

EXECUTE;

! Actions Block

ENDOFF;
RUNTIME;
BKCOLOR=1;
ACTIONS


!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                                                !
!  This section determines the work orders to be scheduled for   !
!  the first future month.  This is done in the same fashion as  !
!  the current month.  The available shop hours are retrieved    !
!  from the IWP_Shops data file for each shop, and material      !
!  complete work orders not yet scheduled are scheduled against  !
!  them in priority order.                                       !
!                                                                !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

LOADFACTS c:\vpxp\iwptemp
FIND First_Future_Month
FIND Year_of_First_Future_Month
FORMAT First_Future_Month,2.0

Test = 1
WHILETRUE Test > 0 THEN
   RESET shop433hrs
   RESET shop441hrs
   RESET shop443hrs
   RESET shop451hrs
   RESET shop452hrs
   RESET shop453hrs
   RESET shop454hrs
   RESET shop456hrs
   RESET shop457hrs
   RESET shop461hrs
   RESET shop462hrs
   RESET shop463hrs
   RESET shop464hrs
```

```
   RESET shop465hrs
   RESET shop468hrs
   RESET shop469hrs
   RESET shop471hrs
   RESET shop472hrs
   RESET shop480hrs
   RESET shop493hrs

    GET First_Future_Month=IWP_Month AND
Year_of_First_Future_Month=IWP_Year,iwpshops,all

      FIND shop433hrs
      FIND shop441hrs
      FIND shop443hrs
      FIND shop451hrs
      FIND shop452hrs
      FIND shop453hrs
      FIND shop454hrs
      FIND shop456hrs
      FIND shop457hrs
      FIND shop461hrs
      FIND shop462hrs
      FIND shop463hrs
      FIND shop464hrs
      FIND shop465hrs
      FIND shop468hrs
      FIND shop469hrs
      FIND shop471hrs
      FIND shop472hrs
      FIND shop480hrs
      FIND shop493hrs

      Test = 0
      CLOSE iwpshops
END

COLOR = 7
DISPLAY "The available hours for the shops for
{Year_of_First_Future_Month}{First_Future_Month} are:"
DISPLAY " "
DISPLAY "          Shop 433  =  {shop433hrs}
          Shop 441  =  {shop441hrs}
          Shop 443  =  {shop443hrs}
          Shop 451  =  {shop451hrs}
          Shop 452  =  {shop452hrs}
          Shop 453  =  {shop453hrs}
          Shop 454  =  {shop454hrs}
          Shop 456  =  {shop456hrs}
          Shop 457  =  {shop457hrs}
          Shop 461  =  {shop461hrs}
          Shop 462  =  {shop462hrs}
          Shop 463  =  {shop463hrs}
          Shop 464  =  {shop464hrs}
```

```
            Shop 465  =  {shop465hrs}
            Shop 468  =  {shop468hrs}
            Shop 469  =  {shop469hrs}
            Shop 471  =  {shop471hrs}
            Shop 472  =  {shop472hrs}
            Shop 480  =  {shop480hrs}
            Shop 493  =  {shop493hrs}"

DISPLAY " "
DISPLAY "I will now calculate and display hours for
the second future month"
DISPLAY " "
DISPLAY "Press any key to continue~"

CLS

      ffm_shop433_remaining_hours = (shop433hrs)
      ffm_shop441_remaining_hours = (shop441hrs)
      ffm_shop443_remaining_hours = (shop443hrs)
      ffm_shop451_remaining_hours = (shop451hrs)
      ffm_shop452_remaining_hours = (shop452hrs)
      ffm_shop453_remaining_hours = (shop453hrs)
      ffm_shop454_remaining_hours = (shop454hrs)
      ffm_shop456_remaining_hours = (shop456hrs)
      ffm_shop457_remaining_hours = (shop457hrs)
      ffm_shop461_remaining_hours = (shop461hrs)
      ffm_shop462_remaining_hours = (shop462hrs)
      ffm_shop463_remaining_hours = (shop463hrs)
      ffm_shop464_remaining_hours = (shop464hrs)
      ffm_shop465_remaining_hours = (shop465hrs)
      ffm_shop468_remaining_hours = (shop468hrs)
      ffm_shop469_remaining_hours = (shop469hrs)
      ffm_shop471_remaining_hours = (shop471hrs)
      ffm_shop472_remaining_hours = (shop472hrs)
      ffm_shop480_remaining_hours = (shop480hrs)
      ffm_shop493_remaining_hours = (shop493hrs)

WHILEKNOWN Wonumber
  Not_Scheduled = 99
  GET Not_Scheduled = IWP_Month AND Not_Scheduled =
IWP_Year,iwpsort,all
      FIND ffm_shop433_remaining_hours
      FIND ffm_shop441_remaining_hours
      FIND ffm_shop443_remaining_hours
      FIND ffm_shop451_remaining_hours
      FIND ffm_shop452_remaining_hours
      FIND ffm_shop453_remaining_hours
      FIND ffm_shop454_remaining_hours
      FIND ffm_shop456_remaining_hours
      FIND ffm_shop457_remaining_hours
      FIND ffm_shop461_remaining_hours
      FIND ffm_shop462_remaining_hours
      FIND ffm_shop463_remaining_hours
```

```
      FIND ffm_shop464_remaining_hours
      FIND ffm_shop465_remaining_hours
      FIND ffm_shop468_remaining_hours
      FIND ffm_shop469_remaining_hours
      FIND ffm_shop471_remaining_hours
      FIND ffm_shop472_remaining_hours
      FIND ffm_shop480_remaining_hours
      FIND ffm_shop493_remaining_hours
      RESET First_Future_IWP_Month
      RESET Year_of_First_Future_IWP_Month
      FIND First_Future_IWP_Month
      FIND Year_of_First_Future_IWP_Month


      IWP_Year = (Year_of_First_Future_IWP_Month)
      IWP_Month = (First_Future_IWP_Month)
      PUT iwpsort
    FIND Wonumber
END
CLOSE iwpsort

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                                           !
!  This section determines the work orders to be scheduled  !
!  for the first future month.  This is done in the same    !
!  fashion as the current month.  The available shop hours  !
!  are retrieved from the IWP_Shops data file for each      !
!  shop, and material complete work orders not yet          !
!  scheduled are scheduled against them in priority order.  !
!                                                           !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

FIND Second_Future_Month
FIND Year_of_Second_Future_Month
FORMAT Second_Future_Month,2.0

Test = 1
WHILETRUE Test > 0 THEN
   RESET shop433hrs
   RESET shop441hrs
   RESET shop443hrs
   RESET shop451hrs
   RESET shop452hrs
   RESET shop453hrs
   RESET shop454hrs
   RESET shop456hrs
   RESET shop457hrs
   RESET shop461hrs
   RESET shop462hrs
   RESET shop463hrs
   RESET shop464hrs
   RESET shop465hrs
```

```
   RESET shop468hrs
   RESET shop469hrs
   RESET shop471hrs
   RESET shop472hrs
   RESET shop480hrs
   RESET shop493hrs

      GET Second_Future_Month=IWP_Month AND
Year_of_Second_Future_Month=IWP_Year,
          iwpshops,all

      FIND shop433hrs
      FIND shop441hrs
      FIND shop443hrs
      FIND shop451hrs
      FIND shop452hrs
      FIND shop453hrs
      FIND shop454hrs
      FIND shop456hrs
      FIND shop457hrs
      FIND shop461hrs
      FIND shop462hrs
      FIND shop463hrs
      FIND shop464hrs
      FIND shop465hrs
      FIND shop468hrs
      FIND shop469hrs
      FIND shop471hrs
      FIND shop472hrs
      FIND shop480hrs
      FIND shop493hrs

      Test = 0
      CLOSE iwpshops

END

DISPLAY "The available hours for the shops for
{Year_of_Second_Future_Month} {Second_Future_Month} are:"
DISPLAY " "
DISPLAY "         Shop 433  =  {shop433hrs}
          Shop 441  =  {shop441hrs}
          Shop 443  =  {shop443hrs}
          Shop 451  =  {shop451hrs}
          Shop 452  =  {shop452hrs}
          Shop 453  =  {shop453hrs}
          Shop 454  =  {shop454hrs}
          Shop 456  =  {shop456hrs}
          Shop 457  =  {shop457hrs}
          Shop 461  =  {shop461hrs}
          Shop 462  =  {shop462hrs}
          Shop 463  =  {shop463hrs}
          Shop 464  =  {shop464hrs}
```

```
          Shop 465  =  {shop465hrs}
          Shop 468  =  {shop468hrs}
          Shop 469  =  {shop469hrs}
          Shop 471  =  {shop471hrs}
          Shop 472  =  {shop472hrs}
          Shop 480  =  {shop480hrs}
          Shop 493  =  {shop493hrs}"

DISPLAY " "
DISPLAY "Press any key to continue~"
CLS

      sfm_shop433_remaining_hours = (shop433hrs)
      sfm_shop441_remaining_hours = (shop441hrs)
      sfm_shop443_remaining_hours = (shop443hrs)
      sfm_shop451_remaining_hours = (shop451hrs)
      sfm_shop452_remaining_hours = (shop452hrs)
      sfm_shop453_remaining_hours = (shop453hrs)
      sfm_shop454_remaining_hours = (shop454hrs)
      sfm_shop456_remaining_hours = (shop456hrs)
      sfm_shop457_remaining_hours = (shop457hrs)
      sfm_shop461_remaining_hours = (shop461hrs)
      sfm_shop462_remaining_hours = (shop462hrs)
      sfm_shop463_remaining_hours = (shop463hrs)
      sfm_shop464_remaining_hours = (shop464hrs)
      sfm_shop465_remaining_hours = (shop465hrs)
      sfm_shop468_remaining_hours = (shop468hrs)
      sfm_shop469_remaining_hours = (shop469hrs)
      sfm_shop471_remaining_hours = (shop471hrs)
      sfm_shop472_remaining_hours = (shop472hrs)
      sfm_shop480_remaining_hours = (shop480hrs)
      sfm_shop493_remaining_hours = (shop493hrs)

WHILEKNOWN Wonumber
  GET Not_Scheduled = IWP_Month AND Not_Scheduled =
IWP_Year,iwpsort,all

      FIND sfm_shop433_remaining_hours
      FIND sfm_shop441_remaining_hours
      FIND sfm_shop443_remaining_hours
      FIND sfm_shop451_remaining_hours
      FIND sfm_shop452_remaining_hours
      FIND sfm_shop453_remaining_hours
      FIND sfm_shop454_remaining_hours
      FIND sfm_shop456_remaining_hours
      FIND sfm_shop457_remaining_hours
      FIND sfm_shop461_remaining_hours
      FIND sfm_shop462_remaining_hours
      FIND sfm_shop463_remaining_hours
      FIND sfm_shop464_remaining_hours
      FIND sfm_shop465_remaining_hours
      FIND sfm_shop468_remaining_hours
      FIND sfm_shop469_remaining_hours
```

```
      FIND sfm_shop471_remaining_hours
      FIND sfm_shop472_remaining_hours
      FIND sfm_shop480_remaining_hours
      FIND sfm_shop493_remaining_hours

      RESET Second_Future_IWP_Month
      RESET Year_of_Second_Future_IWP_Month
      FIND Second_Future_IWP_Month
      FIND Year_of_Second_Future_IWP_Month

      IWP_Year = (Year_of_Second_Future_IWP_Month)
      IWP_Month = (Second_Future_IWP_Month)
      PUT iwpsort
    FIND Wonumber
END
CLOSE iwpsort

PRINTON
DISPLAY "The IWP Schedule for {This_Year} {This_Month} is:"
DISPLAY " "
DISPLAY "WO_Number  IWP_Start_Date  Com_Intrst  Weather  Date_In
Priority  Score "
DISPLAY "-------------------------------------------------------------"
WHILEKNOWN Wonumber
   GET This_month = IWP_Month,iwpsort,all
   FORMAT Wonumber,5.0
   FORMAT IWP_Month,2.0
   FORMAT IWP_Year,2.0
   FORMAT Yr_in_syst,2.0
   FORMAT mo_in_syst,2.0
   FORMAT priority,1.0
   FORMAT score,5.1

   DISPLAY "{Wonumber}          {IWP_Year} {IWP_Month}
{Comintrst} ^G        {Weather}      {Yr_in_Syst} {Mo_in_Syst}
{Priority}     {Score}"
 FIND Wonumber
END
CLOSE iwpsort

WHILEKNOWN Wonumber
   GET First_Future_month = IWP_Month,iwpsort,all
   FORMAT Wonumber,5.0
   FORMAT IWP_Month,2.0
   FORMAT IWP_Year,2.0
   FORMAT Yr_in_syst,2.0
   FORMAT mo_in_syst,2.0
   FORMAT priority,1.0
   FORMAT score,5.1

   DISPLAY "{Wonumber}          {IWP_Year} {IWP_Month}
{Comintrst} ^G        {Weather}      {Yr_in_Syst} {Mo_in_Syst}
{Priority}     {Score}"
```

```
   FIND Wonumber
END
CLOSE iwpsort

WHILEKNOWN Wonumber
   GET Second_Future_month = IWP_Month,iwpsort,all
   FORMAT Wonumber,5.0
   FORMAT IWP_Month,2.0
   FORMAT IWP_Year,2.0
   FORMAT Yr_in_syst,2.0
   FORMAT mo_in_syst,2.0
   FORMAT priority,1.0
   FORMAT score,5.1

   DISPLAY "{Wonumber}          {IWP_Year} {IWP_Month}
{Comintrst} ^G          {Weather}       {Yr_in_Syst} {Mo_in_Syst}
{Priority}     {Score}"

   FIND Wonumber
END
CLOSE iwpsort

WHILEKNOWN Wonumber
   GET Not_Scheduled = IWP_Month,iwpsort,all
   FORMAT Wonumber,5.0
   FORMAT IWP_Month,2.0
   FORMAT IWP_Year,2.0
   FORMAT Yr_in_syst,2.0
   FORMAT mo_in_syst,2.0
   FORMAT priority,1.0
   FORMAT score,5.1

   DISPLAY "{Wonumber}          {IWP_Year} {IWP_Month}
{Comintrst} ^G          {Weather}       {Yr_in_Syst} {Mo_in_Syst}
{Priority}     {Score}"
   FIND Wonumber
END
CLOSE iwpsort
PRINTOFF
DISPLAY " "
DISPLAY "Press any key to continue ~"
cls

FORMAT Shop433_remaining_hours,6.1
FORMAT Shop441_remaining_hours,6.1
FORMAT Shop443_remaining_hours,6.1
FORMAT Shop451_remaining_hours,6.1
FORMAT Shop452_remaining_hours,6.1
FORMAT Shop453_remaining_hours,6.1
FORMAT Shop454_remaining_hours,6.1
FORMAT Shop456_remaining_hours,6.1
FORMAT Shop457_remaining_hours,6.1
FORMAT Shop461_remaining_hours,6.1
```

```
FORMAT Shop462_remaining_hours,6.1
FORMAT Shop463_remaining_hours,6.1
FORMAT Shop464_remaining_hours,6.1
FORMAT Shop465_remaining_hours,6.1
FORMAT Shop468_remaining_hours,6.1
FORMAT Shop469_remaining_hours,6.1
FORMAT Shop471_remaining_hours,6.1
FORMAT Shop472_remaining_hours,6.1
FORMAT Shop480_remaining_hours,6.1
FORMAT Shop493_remaining_hours,6.1

FORMAT ffm_Shop433_remaining_hours,6.1
FORMAT ffm_Shop441_remaining_hours,6.1
FORMAT ffm_Shop443_remaining_hours,6.1
FORMAT ffm_Shop451_remaining_hours,6.1
FORMAT ffm_Shop452_remaining_hours,6.1
FORMAT ffm_Shop453_remaining_hours,6.1
FORMAT ffm_Shop454_remaining_hours,6.1
FORMAT ffm_Shop456_remaining_hours,6.1
FORMAT ffm_Shop457_remaining_hours,6.1
FORMAT ffm_Shop461_remaining_hours,6.1
FORMAT ffm_Shop462_remaining_hours,6.1
FORMAT ffm_Shop463_remaining_hours,6.1
FORMAT ffm_Shop464_remaining_hours,6.1
FORMAT ffm_Shop465_remaining_hours,6.1
FORMAT ffm_Shop468_remaining_hours,6.1
FORMAT ffm_Shop469_remaining_hours,6.1
FORMAT ffm_Shop471_remaining_hours,6.1
FORMAT ffm_Shop472_remaining_hours,6.1
FORMAT ffm_Shop480_remaining_hours,6.1
FORMAT ffm_Shop493_remaining_hours,6.1

FORMAT sfm_Shop433_remaining_hours,6.1
FORMAT sfm_Shop441_remaining_hours,6.1
FORMAT sfm_Shop443_remaining_hours,6.1
FORMAT sfm_Shop451_remaining_hours,6.1
FORMAT sfm_Shop452_remaining_hours,6.1
FORMAT sfm_Shop453_remaining_hours,6.1
FORMAT sfm_Shop454_remaining_hours,6.1
FORMAT sfm_Shop456_remaining_hours,6.1
FORMAT sfm_Shop457_remaining_hours,6.1
FORMAT sfm_Shop461_remaining_hours,6.1
FORMAT sfm_Shop462_remaining_hours,6.1
FORMAT sfm_Shop463_remaining_hours,6.1
FORMAT sfm_Shop464_remaining_hours,6.1
FORMAT sfm_Shop465_remaining_hours,6.1
FORMAT sfm_Shop468_remaining_hours,6.1
FORMAT sfm_Shop469_remaining_hours,6.1
FORMAT sfm_Shop471_remaining_hours,6.1
FORMAT sfm_Shop472_remaining_hours,6.1
FORMAT sfm_Shop480_remaining_hours,6.1
FORMAT sfm_Shop493_remaining_hours,6.1
```

```
PRINTON
DISPLAY "The remaining hours for each shop for these months are:"
DISPLAY " "
DISPLAY "  Shop      Current Month    1st Future Month    2nd Future
Month"
DISPLAY "------------------------------------------------------------"
DISPLAY "  433          {Shop433_remaining_hours}
^G{ffm_shop433_remaining_hours}
{sfm_shop433_remaining_hours}"
DISPLAY "  441          {Shop441_remaining_hours}
^G{ffm_shop441_remaining_hours}
{sfm_shop441_remaining_hours}"
DISPLAY "  443          {Shop443_remaining_hours}
^G{ffm_shop443_remaining_hours}
{sfm_shop443_remaining_hours}"
DISPLAY "  451          {Shop451_remaining_hours}
^G{ffm_shop451_remaining_hours}
{sfm_shop451_remaining_hours}"
DISPLAY "  452          {Shop452_remaining_hours}
^G{ffm_shop452_remaining_hours}
{sfm_shop452_remaining_hours}"
DISPLAY "  453          {Shop453_remaining_hours}
^G{ffm_shop453_remaining_hours}
{sfm_shop453_remaining_hours}"
DISPLAY "  454          {Shop454_remaining_hours}
^G{ffm_shop454_remaining_hours}
{sfm_shop454_remaining_hours}"
DISPLAY "  456          {Shop456_remaining_hours}
^G{ffm_shop456_remaining_hours}
{sfm_shop456_remaining_hours}"
DISPLAY "  457          {Shop457_remaining_hours}
^G{ffm_shop457_remaining_hours}
{sfm_shop457_remaining_hours}"
DISPLAY "  461          {Shop461_remaining_hours}
^G{ffm_shop461_remaining_hours}
{sfm_shop461_remaining_hours}"
DISPLAY "  462          {Shop462_remaining_hours}
^G{ffm_shop462_remaining_hours}
{sfm_shop462_remaining_hours}"
DISPLAY "  463          {Shop463_remaining_hours}
^G{ffm_shop463_remaining_hours}
{sfm_shop463_remaining_hours}"
DISPLAY "  464          {Shop464_remaining_hours}
^G{ffm_shop464_remaining_hours}
{sfm_shop464_remaining_hours}"
DISPLAY "  465          {Shop465_remaining_hours}
^G{ffm_shop465_remaining_hours}
{sfm_shop465_remaining_hours}"
DISPLAY "  468          {Shop468_remaining_hours}
^G{ffm_shop468_remaining_hours}
{sfm_shop468_remaining_hours}"
DISPLAY "  469          {Shop469_remaining_hours}
^G{ffm_shop469_remaining_hours}
```

```
{sfm_shop469_remaining_hours}"
DISPLAY "  471        {Shop471_remaining_hours}
^G{ffm_shop471_remaining_hours}
{sfm_shop471_remaining_hours}"
DISPLAY "  472        {Shop472_remaining_hours}
^G{ffm_shop472_remaining_hours}
{sfm_shop472_remaining_hours}"
DISPLAY "  480        {Shop480_remaining_hours}
^G{ffm_shop480_remaining_hours}
{sfm_shop480_remaining_hours}"
DISPLAY "  493        {Shop493_remaining_hours}
^G{ffm_shop493_remaining_hours}
{sfm_shop493_remaining_hours}"
PRINTOFF
DISPLAY " "
DISPLAY "Press any key to finish ~"
cls
;


! Rules Block

RULE 1
IF    Priority = 1
THEN  Priority_Factor = 13;

RULE 2
IF    Priority = 2
THEN  Priority_Factor = 5;

RULE 3
IF    Priority = 3
THEN  Priority_Factor = 2;

RULE 4
IF    Priority = 4
THEN  Priority_Factor = 1;

RULE 5
IF    Comintrst = y
THEN  Command_Factor = 1.6
ELSE  Command_Factor = 1.0;

RULE 6
IF    Weather = n
THEN  Weather_Factor = 1;

RULE 7
IF    Weather = y
AND   Conditions = Good
THEN  Weather_Factor = 2 CNF 80;
```

```
RULE 8
IF    Weather = y
AND   Conditions = Bad
THEN  Weather_Factor = 0 CNF 80;

RULE 9
IF    Fundsite = 1
THEN  Fundsite_Factor = 1.6;

RULE 10
IF    Fundsite = 2
THEN  Fundsite_Factor = 1.3;

RULE 11
IF    Fundsite = 3
THEN  Fundsite_Factor = 1.4;

RULE 12
IF    Fundsite = 4
THEN  Fundsite_Factor = 1;

RULE 13
IF    Status = mc
THEN  Status_Factor = 1 CNF 90
ELSE  Status_Factor = 0 CNF 100;

RULE 14
IF    Worksite = y
THEN  Worksite_Factor = 1
ELSE  Worksite_Factor = 0;


RULE 16
IF This_Month < 12
THEN First_Future_Month = (This_Month + 01)
     Year_of_First_Future_Month = (This_Year)
ELSE First_Future_Month = 01
     Year_of_First_Future_Month = (This_Year + 1);

RULE 17
IF First_Future_Month < 12
THEN Second_Future_Month = (First_Future_Month + 01)
     Year_of_Second_Future_Month = (Year_of_First_Future_Month)
ELSE Second_Future_Month = 01
     Year_of_Second_Future_Month = (Year_of_First_Future_Month +
01);
```

```
RULE 18
IF  shop433 <= (ffm_shop433_remaining_hours)
AND shop441 <= (ffm_shop441_remaining_hours)
AND shop443 <= (ffm_shop443_remaining_hours)
AND shop451 <= (ffm_shop451_remaining_hours)
AND shop452 <= (ffm_shop452_remaining_hours)
AND shop453 <= (ffm_shop453_remaining_hours)
AND shop454 <= (ffm_shop454_remaining_hours)
AND shop456 <= (ffm_shop456_remaining_hours)
AND shop457 <= (ffm_shop457_remaining_hours)
AND shop461 <= (ffm_shop461_remaining_hours)
AND shop462 <= (ffm_shop462_remaining_hours)
AND shop463 <= (ffm_shop463_remaining_hours)
AND shop464 <= (ffm_shop464_remaining_hours)
AND shop465 <= (ffm_shop465_remaining_hours)
AND shop468 <= (ffm_shop468_remaining_hours)
AND shop469 <= (ffm_shop469_remaining_hours)
AND shop471 <= (ffm_shop471_remaining_hours)
AND shop472 <= (ffm_shop472_remaining_hours)
AND shop480 <= (ffm_shop480_remaining_hours)
AND shop493 <= (ffm_shop493_remaining_hours)

THEN First_Future_IWP_Month = (First_Future_Month)
     Year_of_First_Future_IWP_Month  =
         (Year_of_First_Future_Month)
  ffm_shop433_remaining_hours =
       (ffm_shop433_remaining_hours - shop433)
  ffm_shop441_remaining_hours =
       (ffm_shop441_remaining_hours - shop441)
  ffm_shop443_remaining_hours =
       (ffm_shop443_remaining_hours - shop443)
  ffm_shop451_remaining_hours =
       (ffm_shop451_remaining_hours - shop451)
  ffm_shop452_remaining_hours =
       (ffm_shop452_remaining_hours - shop452)
  ffm_shop453_remaining_hours =
       (ffm_shop453_remaining_hours - shop453)
  ffm_shop454_remaining_hours =
       (ffm_shop454_remaining_hours - shop454)
  ffm_shop456_remaining_hours =
       (ffm_shop456_remaining_hours - shop456)
  ffm_shop457_remaining_hours =
       (ffm_shop457_remaining_hours - shop457)
  ffm_shop461_remaining_hours =
       (ffm_shop461_remaining_hours - shop461)
  ffm_shop462_remaining_hours =
       (ffm_shop462_remaining_hours - shop462)
  ffm_shop463_remaining_hours =
       (ffm_shop463_remaining_hours - shop463)
  ffm_shop464_remaining_hours =
       (ffm_shop464_remaining_hours - shop464)
  ffm_shop465_remaining_hours =
       (ffm_shop465_remaining_hours - shop465)
```

```
 ffm_shop468_remaining_hours =
      (ffm_shop468_remaining_hours - shop468)
 ffm_shop469_remaining_hours =
      (ffm_shop469_remaining_hours - shop469)
 ffm_shop471_remaining_hours =
      (ffm_shop471_remaining_hours - shop471)
 ffm_shop472_remaining_hours =
      (ffm_shop472_remaining_hours - shop472)
 ffm_shop480_remaining_hours =
      (ffm_shop480_remaining_hours - shop480)
 ffm_shop493_remaining_hours =
      (ffm_shop493_remaining_hours - shop493)
ELSE First_Future_IWP_Month = 99
     Year_of_First_Future_IWP_Month = 99;


RULE 19
IF  shop433 <= (sfm_shop433_remaining_hours)
AND shop441 <= (sfm_shop441_remaining_hours)
AND shop443 <= (sfm_shop443_remaining_hours)
AND shop451 <= (sfm_shop451_remaining_hours)
AND shop452 <= (sfm_shop452_remaining_hours)
AND shop453 <= (sfm_shop453_remaining_hours)
AND shop454 <= (sfm_shop454_remaining_hours)
AND shop456 <= (sfm_shop456_remaining_hours)
AND shop457 <= (sfm_shop457_remaining_hours)
AND shop461 <= (sfm_shop461_remaining_hours)
AND shop462 <= (sfm_shop462_remaining_hours)
AND shop463 <= (sfm_shop463_remaining_hours)
AND shop464 <= (sfm_shop464_remaining_hours)
AND shop465 <= (sfm_shop465_remaining_hours)
AND shop468 <= (sfm_shop468_remaining_hours)
AND shop469 <= (sfm_shop469_remaining_hours)
AND shop471 <= (sfm_shop471_remaining_hours)
AND shop472 <= (sfm_shop472_remaining_hours)
AND shop480 <= (sfm_shop480_remaining_hours)
AND shop493 <= (sfm_shop493_remaining_hours)

THEN Second_Future_IWP_Month = (Second_Future_Month)
     Year_of_Second_Future_IWP_Month  =
          (Year_of_Second_Future_Month)
 sfm_shop433_remaining_hours =
      (sfm_shop433_remaining_hours - shop433)
 sfm_shop441_remaining_hours =
      (sfm_shop441_remaining_hours - shop441)
 sfm_shop443_remaining_hours =
      (sfm_shop443_remaining_hours - shop443)
 sfm_shop451_remaining_hours =
      (sfm_shop451_remaining_hours - shop451)
 sfm_shop452_remaining_hours =
      (sfm_shop452_remaining_hours - shop452)
 sfm_shop453_remaining_hours =
      (sfm_shop453_remaining_hours - shop453)
```

```
sfm_shop454_remaining_hours =
     (sfm_shop454_remaining_hours - shop454)
sfm_shop456_remaining_hours =
     (sfm_shop456_remaining_hours - shop456)
sfm_shop457_remaining_hours =
     (sfm_shop457_remaining_hours - shop457)
sfm_shop461_remaining_hours =
     (sfm_shop461_remaining_hours - shop461)
sfm_shop462_remaining_hours =
     (sfm_shop462_remaining_hours - shop462)
sfm_shop463_remaining_hours =
     (sfm_shop463_remaining_hours - shop463)
sfm_shop464_remaining_hours =
     (sfm_shop464_remaining_hours - shop464)
sfm_shop465_remaining_hours =
     (sfm_shop465_remaining_hours - shop465)
sfm_shop468_remaining_hours =
     (sfm_shop468_remaining_hours - shop468)
sfm_shop469_remaining_hours =
     (sfm_shop469_remaining_hours - shop469)
sfm_shop471_remaining_hours =
     (sfm_shop471_remaining_hours - shop471)
sfm_shop472_remaining_hours =
     (sfm_shop472_remaining_hours - shop472)
sfm_shop480_remaining_hours =
     (sfm_shop480_remaining_hours - shop480)
sfm_shop493_remaining_hours =
     (sfm_shop493_remaining_hours - shop493)

ELSE Second_Future_IWP_Month = 99
     Year_of_Second_Future_IWP_Month = 99;
```

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VITA

Captain Phillip W. Melancon was born on 26 August 1964 in Fairfax, VA. He graduated from high school in Thibodaux, Louisiana, in 1982, then attended Louisiana State University on an ROTC scholarship. He received a Bachelor of Science degree in Industrial Engineering in December, 1986, and was commissioned in the USAF.

Captain Melancon was assigned to the 375th Civil Engineering Squadron at Scott AFB, Illinois where he served as Officer in Charge of the Work Information Management System until 1988. He then served as Chief of Industrial Engineering until December, 1989, then as Chief of Readiness until entering the School of Systems and Logistics, Air Force Institute of Technology, in May, 1990.

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13. ABSTRACT *(Maximum 200 words)* Civil Engineering managers make many decisions each day which could be aided using expert system technology. One of the most important decision processes affecting Civil Engineering Operations is the scheduling of work orders to be accomplished each month. A good work order schedule, or In-Service Work Plan (IWP), can ensure that material and manpower resources are fully utilized, that base facilities are properly maintained, and that customers are satisfied. The purpose of this research was to build and test a PC-based prototype expert system to schedule the IWP. Expanding on previous research, a multiplicative weighting technique was developed to provide relative scores for each work order awaiting scheduling. Factors used in assigning scores include work order priority, command interest, weather dependency, bottleneck shop availability, and work site availability. The expert system then scheduled work orders against available shop hours, attempting to schedule the work orders with the highest scores first. The prototype produced a three-month schedule in thirty minutes, compared to the four man-weeks required to produce a one-month schedule manually at the test location. The system ensured that high priority work was scheduled first and that bottleneck shops were fully utilized.

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